ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

West African Power Pool

Master Thesis

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# Electricity supply in West Africa: between bilateral agreements and a single regional market

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## Abstract

It is necessary to specify that this study is an academic work carried out by a student as part of his master's project. The hypotheses and reasoning made by the student are at the origin of the results obtained.

Energy has a crucial role in the economic development of a nation or region. The states of ECOWAS, have decided to come together to unite for this challenge and offer quality services to the population. WAPP, a specialized institution, decides to interconnect networks in order to pool the resources of the electricity market and offers quality access at a competitive price to the population. It is therefore necessary to strengthen production, distribution and transmission capacities to ensure the coordination of electricity exchanges between member countries.

This study initially consisted in setting up a methodology explaining the progressive approaches that are applied throughout the project. The strategies for expanding the fleet are each analysed: the self-sufficiency strategy including existing imports and bilateral agreements, the strategy applied by WAPP along with variants involving the share of local production for importing countries. The expansion analysis is done with the support of the PlanElec software. An economic and technical comparison is then made on these two strategies, based on the different costs, the different investments, the installed powers by type and the energy produced.

It can be seen that the more the share of local production increases for importing countries, the more interesting the weighted cost of production becomes. But this has a limit demonstrated by the autarkic strategy. Indeed, the countries considered as importers use imports and their weighted cost of production is lower than with a local production share imposed.

From a global economic point of view, it is more interesting to rely on the major energy powers of the sub-region.

With this study, it has been shown that it is more interesting for countries to turn to an open market policy, dependent on the major powers of the region, although politically no country wishes to be totally dependent on another.

## Acknowledgement

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# Introduction

The Economic Community of West African States (ECOWAS) is a West African intergovernmental organization established on 28 May 1975. It has a population of about 300 million inhabitants over an area of about 5 million $km^2$. Its main objective is to promote economic and political cooperation between states.

Energy has a crucial role in the economic development of a nation or region. Without energy there would be no drinking water, no hospitals, no schools, no housing, no means of transport. The states of ECOWAS have decided to come together to unite for this challenge and offer quality services to the population. WAPP, a specialized institution, decides to interconnect the networks in order to share the electricity market and offer quality access at a competitive price to the population. It is therefore necessary to strengthen production, distribution and transmission capacities to ensure the coordination of electricity exchanges between member countries.

This study focuses on production capacities within ECOWAS, the diversity of this region leads to as many opportunities as challenges in the process of market sharing. Therefore, during this work, it will be interesting to see the planning, net present cost and average cost of production of each country, applying an autarkic strategy to each country compared to the WAPP single regional market strategy.

As a first step, a methodology will be established to detail the order of the steps to be followed throughout the work.

Once implemented, the implementation of expansion strategies will be considered and presented, i.e. how planning, objective function and constraints are selected and modelled on the basis of certain assumptions.

To apply modelling, there is some data to recover on the demand of each country, on the supply of each country and a reflection on the current situation of each country. It is necessary to establish a study between 2018 and 2040 following a certain dynamic.

Now that everything is at hand, it is possible to implement the self-sufficient strategy based on the countries' current energy policies, i.e. the resources used and existing bilateral agreements, among others.

This strategy will be compared with the single regional market strategy, which is the strategy adopted by the WAPP, on economic aspects and quality of service. Finally, it will examine how much local production there is in this single regional market.

Finally, an overall comparison will be presented and a discussion on this work will be opened on the limitations of the assumptions made and the results obtained.

# 1. Methodology

Initially, it is necessary to analyse the work done by Hermann Bayem using the PlanElec software and to appropriate it. This makes it possible to make assumptions and clearly develop the methodology that will be applied throughout this study[1].

The methodology makes it possible to establish the main stages of this project, which is the study and comparison of a market open to the entire ECOWAS region with an autarkic market for each member country, here is a description:

## 1.1. Data collection

The data collection is based on several aspects and hypotheses that will allow the study to progress.

### 1.1.1. Demand analysis

For each country, it is very important to determine the annual electricity need and its evolution in time. For this, two important hypothesis are given: the electricity demand corresponds to the energy delivered for the distribution network and a load factor (FC) and a growth rate are fixed for each country.

Each country has a positive economic growth due to the urbanisation, rural migration, demographic growth and the need's evolution. A different discount rate is applied, it depends on the actual situation in the country in 2018. With an indicative load factor for every country and the evolution of the electricity demand in *GWh*, it will be possible to obtain the maximum of the load power needed to insure the demand.

A load factor is higher when the quality of service is good or when it is an industrialized country. On the other hand, it will be lower when there is a weak management of the production or a demand essentially based on the residential sector.

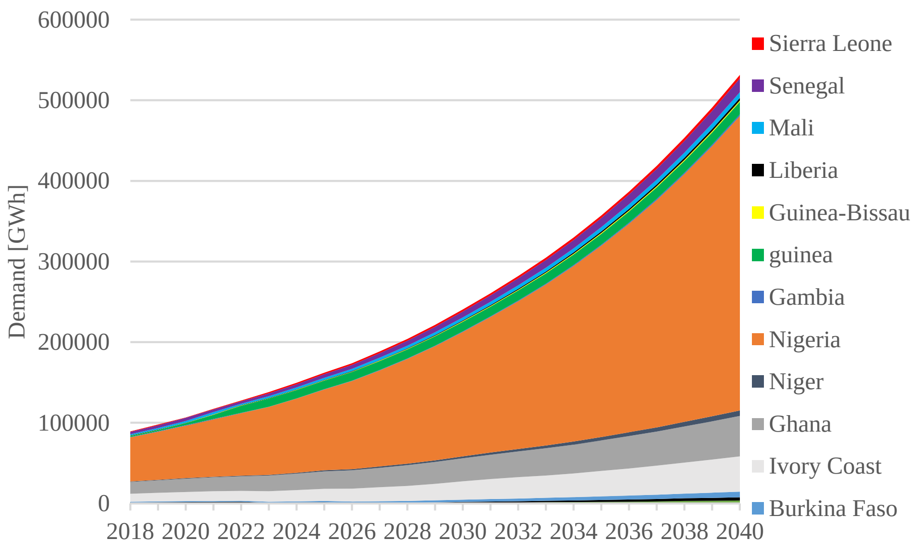


*Figure 1: Annual demand evolution for all countries of the ECOWAS*

With all these indications, it is possible to establish a monotonous load function for each country and to keep it constant for all the study. Below, a summary table illustrates all load factors and growth rates of the electricity demand, until 2040 :

[1] (Herman, 2006)

| Country | Load Factor | Growth rate of the demand |
|---|---|---|
| Benin | 57% | 8.9% |
| Burkina Faso | 55% | 7.3% |
| Ivory Coast | 73% | 6.9% |
| Gambie | 61% | 6.9% |
| Ghana | 70% | 5.8% |
| Guinée | 55% | 7.5% |
| Guinée Bissau | 64% | 7% |
| Libéria | 58% | 8.8% |
| Mali | 69% | 6.6% |
| Niger | 61% | 9% |
| Nigeria | 70% | 9% |
| Sénégal | 69% | 7.3% |
| Sierra Leone | 61% | 8.6% |
| Togo | 72% | 6.5% |

*Table 1:Data and Hypothesis for each country*

#### 1.1.2. Supply analysis

In correlation with the demand, there is the supply. The principal objective is the supply must be high enough to ensure the demand with a good quality service. To study the supply it is necessary to rely on:

- The functional power plant : it represents existing power plants in 2018. It is important to note that the power capacity of the plants is maintained constant until the end of life in PlanElec software. Other essential information concerns the fuel costs, the life cycle, operating costs, annuities. The fuel costs are supposed constant during all the study period. Between 2018 and 2040, the plants for which decommissioning is being carried out will not be renewed but replaced by candidate. Regional power plants are located in the country where they are geographically. For every existing power plant without a year of implementation this year will be taken as 2008. [2]

- The candidate power plants : it is about studying for each country, different power plant opportunities which can be installed depending on the available resources. They will be studied on different aspects : their power, their life cycle, the types of resources, their efficiency and the implementation time. They are classified into two groups :
  - The decided candidate plants : power plants for which there is an implementation year given.
  - The planned candidate plants : power plants unities still in development without a date of implementation.

- Bilateral agreements : they will be taken into account only for the self-sufficient strategy. It is about export or import of electricity for each country. They will be preserved during the study with an eventual increase of the interconnection capacity. An important data to establish is the exchange cost which means the cost of the energy exported. Due to lack of information, these costs are from a 2001 study[3]. If there is an import of electricity in a country, it will be designed by a hydraulic power plant, with a power equal to the line capacity and a life cycle of 1 year on

[2] (ECREEE towards sustainable energy, 2018)
[3] (Ndour, 2001)

Planelec. For the optimisation, import will be considered as a power plant planned, to have the choice to import electricity or to benefit local production.

#### 1.1.3. Economic data

To compare strategies, on the given study period until 2040, it is necessary to work with a representative interest rate for each country. It will be adapted, taking into account the question of the risk aversion to invest in the countries and the business environment: the higher is the risk, the higher will be the rate. For the single regional market, the interest rate will be representative of the actual situation in the region: this value will be taken as 8%. The discount rate proposed is equal to the interest rate of the country, then the risk perception is different for each country, because they have a different interest rate. The money scale is the following :

- 1€ = 1.15 US$
- 1€ = 655.90 FCFA

For each existing and candidate power plants it is important to obtain data about investment costs, O&M costs, fuel costs, the implementation time, interest during the construction (5%). With all these information, the objective function (Net Present Cost) could be minimized with a good quality of service constraint for each strategy. The objective function will be explained mathematically in the part named 2.2.

### 1.2. Analysis of the expansion strategies

#### 1.2.1. The self-sufficient strategy

The self-sufficient strategy is an energy planning based on a supply that answers the national electricity demand, using energy import from boundary countries if agreements exist. An economic optimisation will be realised with a good service quality constraint represented by the *Loss of Load Probability* (LOLP) fixed at 0.6%, which is equal to 2 days per year, and a security margin between 5 and 30% to ensure a good supply quality. For this strategy, bilateral agreements will be kept for the study period. The electricity import will be modelled by a candidate hydraulic power plant: other candidate power plants will be studied for each country, it will depend on the potential of development and energy sources useful in the country or by import. Appointed power plants or candidate power plants with a regional goal will not be modelled for the self-sufficient strategy.

For this analysis, the first step, is to study importer countries, to obtain the quantity of imported energy by these countries. This imported energy will be from an exporter country, member of the ECOWAS (Nigeria, Ghana, Ivory Coast or Guinea). Electricity imports will be added to the exported countries demand, to establish the production to ensure the local demand and the export.

This study will analyse the Eastern zone of the ECOWAS : Benin, Burkina Faso, Ivory-Coast, Ghana, Niger, Nigeria and Togo.

#### 1.2.2. Single regional market analysis

The single regional market represents an electricity market unifying ECOWAS countries. Similarly to the self-sufficient strategy, an economic optimisation will be done. For all the sub-region, the security margin will be lower due to the power plant size. The existing power plants regroup all existing power plants of every country. These power plants will not be renewed after their life cycle. Import power plants (which are designed as a hydraulic power plant in the self-sufficient strategy) will not exist since it is a single unified market. Each existing power plant or future power plants will be named by the country localisation to realize an energy statement of accounts for each one: this will take into account the local production and the energy imported or exported.

### 1.2.3. What is the local production part in the single regional market ?

Finally, a complementary analysis will be possible, modifying the autonomous degree of each country in the single regional market. A percentage of production will be set and the remaining percentage will define the production part of the unified market. With this analysis, it will be interesting to observe the differences concerning the investment costs for each country, the quality of service and the levelized cost of energy.

### 1.2.4. Discussion

Based on the initial hypothesis and obtained results over the period of study, it will be possible to define the limits of the study and the model. Also, this allows to discuss about the viability of the expansion plan in view of perspectives of the future of the ECOWAS.

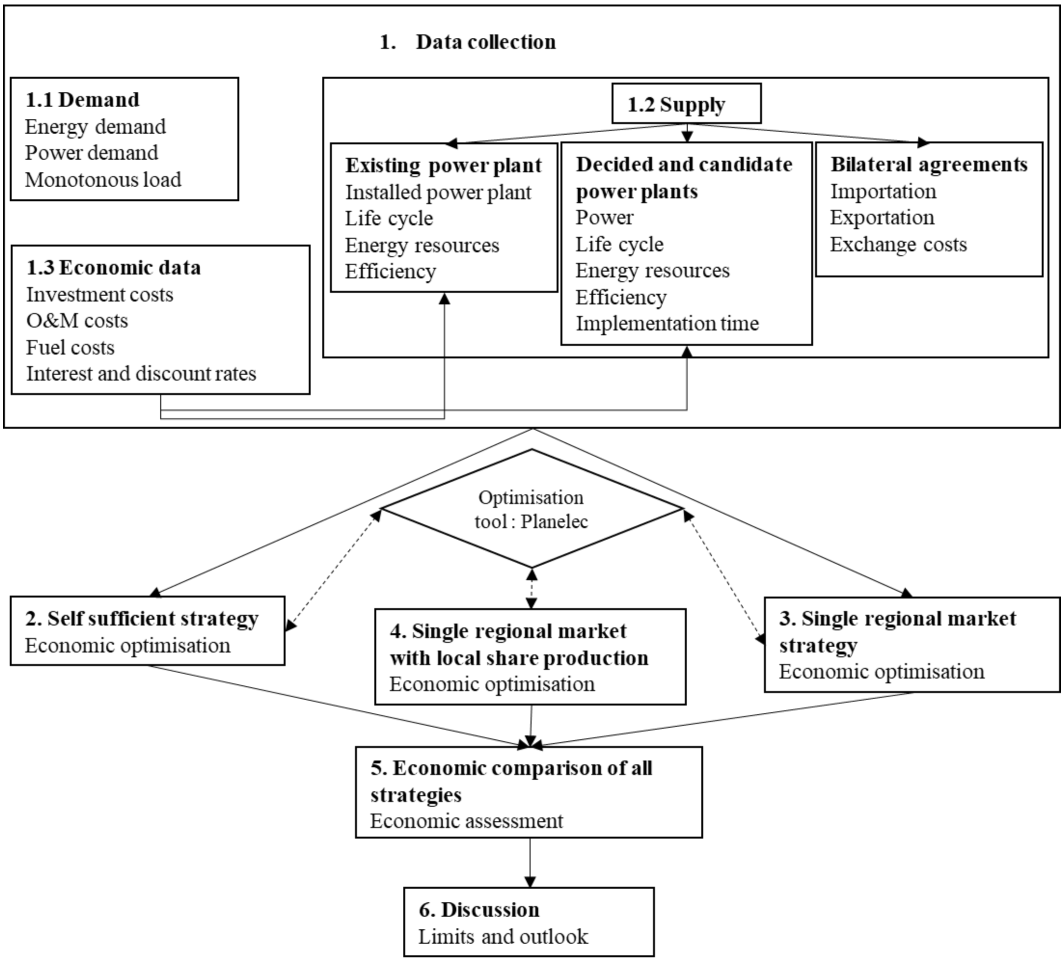


*Figure 2: General procedural method*

# 2. Development of different expansion strategies

## 2.1. Development for an expansion design

To realize these strategy analyses, data will be written in the PlanElec software. Before this step, a short *equilibrium duration method* will be done with candidate power plants for each country to submit a minimal planning of the power plant, to optimize the software using.

For an importer country, the power plant to install each year *t* is equal to the difference between the maximal power demand $P_{max}$, the existing power plant for the year *t*, imported power and power from decided power plant for this year *t*. Which is :

$$P_{\text{à}inst,t} = P_{max,t} - P_{ex,t} - P_{imp,t} - P_{\text{prévue},t};$$

With :

- $P_{\text{à}inst,t}$ : Power to install the year *t* [MW]
- $P_{max,t}$ : Maximal power demand the year *t* [MW]
- $P_{ex,t}$ : Existing power plan the year *t* [MW]
- $P_{imp,t}$ : Imported power the year *t* [MW]
- $P_{\text{prévue},t}$ : Power from decided power plant year *t* [MW]

For an exported country the power to install is equal to :

$$P_{\text{à}inst,t} = P_{max,t} - P_{ex,t} + P_{exp,t} - P_{\text{prévue},t};$$

With :

- $P_{exp,t}$ : Exported power the year *t* [MW]

The equilibrium duration method : For a country to study, it is necessary to know the evolution of electricity needs as said previously. With research and hypothesis on this evolution, it is possible to obtain the maximal power demand, then it is also possible to determine the load factor (cf. Table 1) which corresponds to the integral of the monotonous load function. The latter is the same for every year and is a polynomial function. Factors of this function are adapted with a goal seek operation, to match the ratio $P_{min}/P_{max}$, with a given value for each country (cf. Table 1). Then, you have the power used repartition for all hours of the year.

It is impossible to dismantle all the existing power plants because this results in very important investment costs. The life cycle must be respected and the dismantlement of the power plant must be conducted when needed.

To ensure every country's electricity demand, it is necessary to install new power plants in addition to the existing power plants. These new power plants are the *decided power plants* and *candidate power plants.* For all member countries, depending on the resources, *candidate power plants* can interchange between them. Once the choice is made, a calculation must be conducted, covering the total investment after the implementation with a 5% building rate and an implementation time between 1 and 7 years depending on the power plant size. Annuities, fixed costs, specific consumption, specific costs are also calculated. Fixed costs and annuities are summed by MW which becomes fixed charges (US$/MW), O&M costs are added to specific costs by MWh and form together variable charges (US$/MWh).

With both these charges, it is possible to have the total annual costs depending on the operating time during the year of *candidate power plants.* This total annual costs is a linear affine function : *ax+b*, with *a*, variables charges multiplied by the hours of the year that is *x* between [0 ;8760], and *b* fixed charges. These functions are graphically represented for each candidate power plant, and they have intersection points which correspond to the hours during which a candidate power plant is more interesting than the other crossed. With this method it is possible to define each operating time part for one year.

These operating times parts are the unknown $x_i$ in the function of the monotonous charge. Multiplying the power to install the year *t* by the monotonous charge with a $x_i$ given, the power to install for each candidate power plant *i* is obtained. This is shown in the the mathematical explanation below :

$$Inv_{aprèscons,i} = \frac{Inv_{puis} * (1 + i_c)^{T_c}}{1'000'000} * P_{cent,i} \;;$$

- $Inv_{aprèscons,i}$ : Total investment of the candidate power plant *i* after it implementation [M$]
- $Inv_{puis,i}$ : Investment per MW of power for the candidate power plant *i* [$/MW]
- $i_c$ : Interest rate during the implementation 5%
- $T_{c,i}$ :Implementation time of the candidate power plant *i* [an]
- $P_{cent,i}$ : Power of the candidate power plant *i* [MW]
-

$$A_i = \frac{Inv_{aprèscons,i} * i_{r,p}}{\left(1 - \left(1 + i_{r,p}\right)^{-D_i}\right) * P_{cent,i}} * 1'000'000;$$

- $A_i$ : Annuities of the candidate power plant *i* [$/MW]
- $i_{r,p}$ : Real interest rate of the country *p* [4]
- $D_i$ : Life time of the candidate power plant *i* [an]
-

$$C_{ConsoSpé,i,j,p} = \frac{ConsoSpé_{i,j,p} * Prix_{j,p}}{1'000};$$

- $C_{ConsoSpé,i,j,p}$ : Specific consumption costs of the candidate power plant *i*, using the fuel *j*, in the country *p* [$/MWh]
- $ConsoSpé_{i,j,p}$ : Specific consumption of the candidate power plant *i* using the fuel *j* in the country *p* [kcal/kWh]
- $Prix_{j,p}$ : Fuel price *j*, [$/Gcal]

$$Ch_{fixe,i} = A_i + C_{fixe,exploit,maint,i};$$

- $Ch_{fixe,i}$ : Fixed charges for the candidate power plant *i* [$/MW]
- $C_{fixe,exploit,maint,i}$ : Fixed O&M costs for the candidate power plant *i* [$/MW]

$$Ch_{variable,i} = C_{ConsoSpé,i,j,p} + C_{variable,exploit,maint,i};$$

- $Ch_{variable,i}$ : Variable charges for the candidate power plant *i* [$/MWh]
- $C_{variable,exploit,maint,i}$ : Variable O&M costs of the candidate power plant *i* [$/MWh]

$$C_i = Ch_{fixe,i} + Ch_{variable,i} * x;$$

- $C_i$ : Total annual costs of the candidate power plant *i* [$/MW]
- $x$ : Year time [0 ;8760]

[4] The interest rates will be define depending on the risk aversion of the country.

$$P_{\grave{a}inst,t,i,p} = P_{\grave{a}inst,t,p} * m(x_i);$$

- $P_{\grave{a}inst,t,i,p}$ : Power to install for the year *t*, with the candidate power plant *i* [MW]
- $m(x_i)$ : Monotonous charge applied at the time part $x_i$ of the candidate power plant *i* [-]

To have the number of candidate power plants, one must divide $P_{\grave{a}inst,t,i,p}$ by $P_{cent,i}$ . With the expansion design obtained by this method, it is possible to submit it for the software PlanElec as the minimal configuration.

## 2.2. Optimisation of the expansion design

This optimisation is realized with the PlanEec software, there are three main steps : the generation of possible expansion configurations, the simulation of these configurations and the optimisation of the power plant planning.

### 2.2.1. The generation of configurations

This step is to generate configurations respecting a maximal and minimal security margin of 30% and 5% and also the *LOLP* constraint. Higher is the security margin, higher are investments. The equilibrium duration method allows a first approximation of the minimal configuration year by year. Candidate power plants can be added to ensure the load power.

### 2.2.2. The simulation of configurations[5]

The simulation is based on a probabilistic model which includes different costs, criteria of power plants and the monotonous charge function of the studied country. During simulations, constraints are about the $CO_2$ emissions and *LOLP*. For this work, there are no penalties or constraints on the $CO_2$ because the global power plant will mainly depend on fuel resources.

### 2.2.3. The optimisation of the power plant planning

When conducting the simulations respecting the different constraints, it is possible to calculate the expansion planning and to compare them with the objective function, which has to be minimized.

The objective function :

$$F = \min(NPE) = \sum_{t=2018}^{2040} \left( {D_t}/{(1+a)^{t-2018}} \right);$$

- $F$ : Objective function
- $NPE$ : Net present cost [US$]
- $D_t$ : Costs for the year *t* [US$]
- $a$ : The discount rate

Annual costs $D_t$ are the reunion of these different costs :

[5] (Herman, 2006)

$$D_t = A_t + O\&M_t + CC_t - VR_t + END_t;$$

- $A_t$ : Annual investment costs pour l'année *t* [US$]
- $O\&M_t$ : Variable and fixed O&M costs [US$]
- $CC_t$ : Fuel consumption costs [US$]
- $VR_t$ : Residual value of the power plants [US$]
- $END_t$ : Unserved energy cost during the year *t* [US$]

The objective function is subject to some constraints, which are as follows:

$$k_t = f_t + U_{k,t};$$

$$f_t = k_{t-1} - D_{k,t};$$

$$f_t + U_{kmin,t} \leq k_t \leq f_t + U_{kmax,t};$$

$$(1 + a_t) * P_{dmax} \leq P(k_t) \leq (1 + b_t) * P_{dmax};$$

$$LOLP(k_t) \leq LOLP_{crit}$$

- $k_t$ : Configuration of the power plant for the year *t*
- $f_t$ : Fixed functional system of the power plant for the year *t*
- $U_{k,t}$ : Configuration added to the fixed functional system of the power plant for the year *t*
- $D_{k,t}$ : Decommissioning of power plants for the year *t*
- $U_{kmin(max),t}$ : Minimal (maximal) configuration allowed for the year *t*
- $P_{dmax}$ : Maximal power demand [MW]
- $P(k_t)$ : Installed power with the configuration *k* for the year *t* [MW]
- $a_t$ & $b_t$ : Security margins 5 and 30%
- $LOLP_{crit}$ : Loss Of Load Probability, 0.6%

# 3. Introduction of data

The aim is to present the necessary data to which the methodology and model for implementing the various strategies will be applied. The first data obtained for ECOWAS countries can be found on the Figure 1 and on the Table 1. They will be further specified during the study for the Eastern Zone countries.

The data were obtained with different mathematical models: econometric and technical-economic. Since the econometric model is not ideal for long-term forecasting, a technical-economic model should have been applied for all countries by breaking down demand by sector of activity according to the value added of each sector.

## 3.1. The demand data

The data used are based on a combination of several research and results [6789]. The electricity demand corresponds to the energy delivered for the distribution network in **Error! Reference source not found.**.

### 3.1.1. Benin

Benin's electricity demand is supplied by CEB and SBEE. In recent years the growth in consumption has been about 9% and the load factor 57%. For the demand forecast, the growth in consumption is 6.4% and the load factor remains equal to 57%.

### 3.1.2. Burkina Faso

According to the same source, energy distributed in Burkina Faso increased by an average of 9% between 2004 and 2016. The demand forecast is based on an average consumption growth rate of 7.3%, while the peak forecast is based on a load factor of 55%.

### 3.1.3. Ivory Coast

The last few years of the Ivory Coast have been politically unstable, which has led to irregular growth in many areas, including the growth of electricity consumption. For the entire duration of the study, a growth rate of 6.9% will be applied to the demand forecast with a load factor of 0.73.

### 3.1.4. Ghana

In 30 years the population of Ghana will double, which will threaten the country's current economic progress. The country has experienced a crisis with the end of gas supply through the GAO pipeline. The increase in demand will be less significant than in the first 3 countries mentioned, with 5.8% and a load factor of about 0.75.

### 3.1.5. Niger

By making assumptions about future developments, it is possible to assume an annual demand growth of 9% and a load factor of 0.61 (Tractebel, 2011).

### 3.1.6. Nigeria

[6] (Tractebel, 2011)
[7] (African Development Bank Group, s.d.)
[8] (Energy International Administration, 2018)
[9] (World Bank, 2015)

Due to the lack of data, Nigeria's demand forecasts are based on the master plan prepared by Tractebel in 2011, the growth in electrical energy consumption is 9% and a load factor of 0.70 is used.

### 3.1.7. Togo

Still with the same master plan, the growth in electrical energy consumption for Togo is about 6.5% like Benin but with a better load factor of 72%.

### 3.1.8. Summary report

This part summarizes the energy demand in GWh, the load capacity in MW, the load factor and the electricity growth factor kept constant for each country.

| Country | Benin | | Burkina Faso | | Ivory-Coast | | Ghana | | Niger | | Nigeria | | Togo | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FC / % ↗ | 0.57 | 6.4 | 0.55 | 7.3 | 0.73 | 6.9 | 0.74 | 5.8 | 0.61 | 9 | 0.7 | 9 | 0.72 | 6.5 |
| Year | E | Pmax | E | Pmax | E | Pmax | E | Pmax | E | Pmax | E | Pmax | E | Pmax |
| 2018 | 1309 | 261.0 | 1612 | 334.6 | 9875 | 1544.1 | 14171 | 2170.7 | 1151 | 215.4 | 55985 | 9130.0 | 1583 | 251.2 |
| 2019 | 1399 | 278.9 | 1739 | 361.0 | 10556 | 1650.7 | 14993 | 2296.6 | 1254 | 234.8 | 61024 | 9951.7 | 1685 | 267.5 |
| 2020 | 1494 | 297.9 | 1876 | 389.4 | 11284 | 1764.6 | 15863 | 2429.8 | 1367 | 255.9 | 66516 | 10847.3 | 1795 | 284.9 |
| 2021 | 1597 | 318.3 | 2024 | 420.1 | 12063 | 1886.3 | 16783 | 2570.8 | 1490 | 279.0 | 72502 | 11823.6 | 1912 | 303.4 |
| 2022 | 1706 | 340.1 | 2183 | 453.1 | 12895 | 2016.5 | 17756 | 2719.9 | 1625 | 304.1 | 79027 | 12887.7 | 2036 | 323.1 |
| 2023 | 1822 | 363.3 | 2355 | 488.8 | 13785 | 2155.6 | 18786 | 2877.6 | 1771 | 331.5 | 86140 | 14047.6 | 2168 | 344.1 |
| 2024 | 1947 | 388.2 | 2541 | 527.3 | 14736 | 2304.4 | 19876 | 3044.5 | 1930 | 361.3 | 93893 | 15311.9 | 2309 | 366.5 |
| 2025 | 2080 | 414.7 | 2741 | 568.8 | 15753 | 2463.4 | 21029 | 3221.1 | 2104 | 393.8 | 102343 | 16690.0 | 2459 | 390.3 |
| 2026 | 2222 | 443.1 | 2957 | 613.6 | 16840 | 2633.4 | 22248 | 3408.0 | 2293 | 429.2 | 111554 | 18192.1 | 2619 | 415.7 |
| 2027 | 2374 | 473.4 | 3189 | 662.0 | 18002 | 2815.1 | 23539 | 3605.6 | 2500 | 467.9 | 121594 | 19829.3 | 2789 | 442.7 |
| 2028 | 2537 | 505.7 | 3440 | 714.1 | 19244 | 3009.3 | 24904 | 3814.7 | 2725 | 510.0 | 132537 | 21614.0 | 2971 | 471.5 |
| 2029 | 2710 | 540.3 | 3711 | 770.3 | 20572 | 3216.9 | 26348 | 4036.0 | 2970 | 555.9 | 144465 | 23559.2 | 3164 | 502.2 |
| 2030 | 2896 | 577.3 | 4004 | 831.0 | 21991 | 3438.9 | 27877 | 4270.1 | 3237 | 605.9 | 157467 | 25679.6 | 3369 | 534.8 |
| 2031 | 3093 | 616.7 | 4319 | 896.4 | 23509 | 3676.2 | 29493 | 4517.7 | 3528 | 660.4 | 171639 | 27990.7 | 3588 | 569.6 |
| 2032 | 3305 | 658.9 | 4659 | 967.0 | 25131 | 3929.8 | 31204 | 4779.8 | 3846 | 719.9 | 187087 | 30509.9 | 3822 | 606.6 |
| 2033 | 3531 | 704.0 | 5026 | 1043.2 | 26865 | 4201.0 | 33014 | 5057.0 | 4192 | 784.7 | 203925 | 33255.8 | 4070 | 646.0 |
| 2034 | 3757 | 749.0 | 5393 | 1119.3 | 28719 | 4490.9 | 34929 | 5350.3 | 4569 | 855.3 | 222278 | 36248.8 | 4335 | 688.0 |
| 2035 | 3997 | 796.9 | 5787 | 1201.0 | 30700 | 4800.7 | 36955 | 5660.6 | 4981 | 932.3 | 242283 | 39511.2 | 4616 | 732.7 |
| 2036 | 4253 | 847.9 | 6209 | 1288.7 | 32818 | 5132.0 | 39098 | 5988.9 | 5429 | 1016.2 | 264088 | 43067.2 | 4916 | 780.3 |
| 2037 | 4525 | 902.2 | 6662 | 1382.8 | 35083 | 5486.1 | 41366 | 6336.3 | 5917 | 1107.6 | 287856 | 46943.3 | 5236 | 831.1 |
| 2038 | 4815 | 960.0 | 7149 | 1483.7 | 37504 | 5864.6 | 43765 | 6703.8 | 6450 | 1207.3 | 313763 | 51168.2 | 5576 | 885.1 |
| 2039 | 5123 | 1021.4 | 7670 | 1592.0 | 40091 | 6269.3 | 46303 | 7092.6 | 7030 | 1316.0 | 342002 | 55773.3 | 5939 | 942.6 |
| 2040 | 5451 | 1086.8 | 8230 | 1708.2 | 42858 | 6701.9 | 48989 | 7504.0 | 7663 | 1434.4 | 372782 | 60792.9 | 6325 | 1003.9 |

*Table 2 : Demand between 2018 and 2040 for the Eastern Zone of ECOWAS*

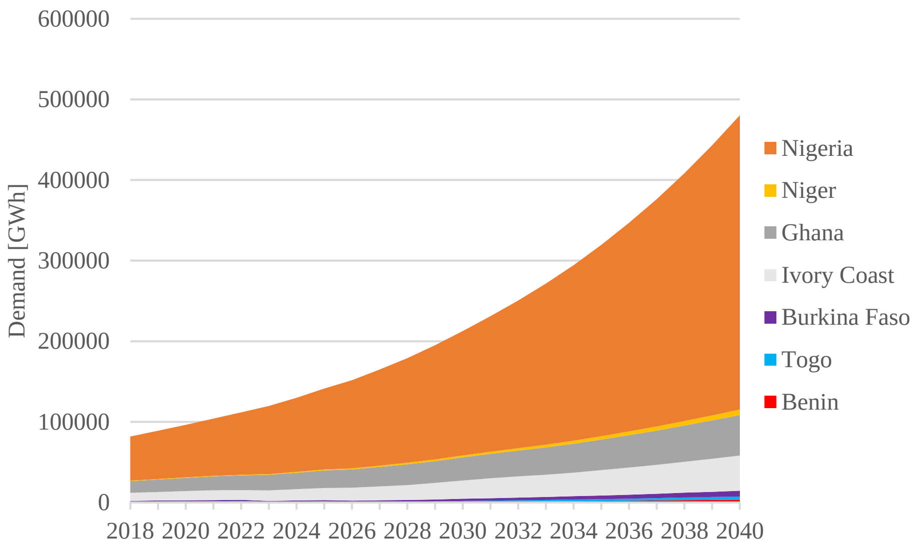


*Figure 3 : The increase in electricity demand between 2018 and 2040*

## 3.2. Supply data[10]

For each country, the power plant on grid and the power plant planned (decided) are presented. The candidate power plants will not be listed, they will be represented by power plant models below in the report.

Bilateral agreements are kept for the self-sufficient strategy and the interconnection lines could be extended to ensure the electricity demand. The imported energy price will be constant throughout the study as well as the discount rate and the interest rate.

As a reminder, every power plant that has reached the end of its life will be dismantled at the corresponding year. It could be renewed but it will be represented by a new power plant that will lead to additional investments.

### 3.2.1. Benin & Togo

Benin and Togo are together because they have some important interconnections and some power plants which are located in one or the other but ensure a production for both. They also have interconnections with Ghana and Nigeria which export electricity energy to Togo and Benin. SBEE and CEB CEET are the main electricity companies. CEB has one hydraulic power plant (Nanbgeto 65MW) based in Togo but working for Togo and Benin. CEB has also two gas turbines, one based in Togo (Lomé 24MW) and the other in Benin (Maria Gleta 24MW), otherwise SBEE and CEET are strictly for their respective country.

In Benin excepted Nangbeto, the power capacity is based on the thermal production : main fuels are the ordinary diesel (DDO) or heavy fuel (HFO), the thermal capacity represents 163MW at the present time.

The thermal capacity production in Togo is composed of gas turbines, and some diesel power plants, with a total installed power of 115MW.

[10] (ECREEE towards sustainable energy, 2018)

| BENIN | | | |
|---|---|---|---|
| Name | Group | Combustible | Capacity [MW] |
| Maria Gleta1 | Gas turbine | DDO | 24 |
| Naitingou | Generator | DDO | 4 |
| Parakou | Generator | DDO | 4 |
| Porto-Novo | Generator | DDO | 6 |
| Parakou | Generator | DDO | 5 |
| Vedoko | Generator | DDO | 20 |
| Akpakpa | Generator | HFO | 35 |
| Gbegamey | Generator | DDO | 15 |
| Maria Gleta2 | Gas turbine | DDO | 50 |

*Table 3 : Existing power capacity in Benin*

| TOGO | | | |
|---|---|---|---|
| Name | Group | Combustible | Capacity [MW] |
| Lomé | Generator | DDO | 20 |
| Contour Global | Gas turbine | NG | 6x15 |
| Lome | Generator | HFO | 5 |
| Nangbeto | Hydraulic | | 2x32.5 |

*Table 4 : Existing power capacity in Togo*

The peak capacity is not ensured by the local existing capacity, Benin and Togo have to import electricity from Ghana and Nigeria. To simplify interconnections, Togo and Benin import the same quantity of energy, that is 200MW from Nigeria and 50MW from Ghana, with an equal repartition.

Most of the existing power capacity will be dismantled before 2040, some projects are decided or planned for Benin and Togo with a hydraulic power plant expansion and better gas line structure to provide some natural gas from Ghana and Nigeria. Their power plants will be represented mainly by gas turbines, combined cycle and hydraulic power plants.

| BENIN | | | |
|---|---|---|---|
| Name | Group | Capacity [MW] | Implementation |
| Maria Gleta | Gas turbine | 50 | 2020 |
| Kétou | Hydraulic | 112 | Planned |
| Beterou | Hydraulic | 23.2 | Planned |
| Vossa | Hydraulic | 79.2 | Planned |
| Oulougbé | Hydraulic | 30 | Planned |

*Table 5 : Decided/Planned projects for Benin*

| TOGO | | | |
|---|---|---|---|
| Name | Group | Capacity [MW] | Implementation |
| Lomé | Gas turbine | 40 | 2020 |
| Adjarala | Hydraulic | 147 | Planned |
| Tétéou | Hydraulic | 50 | Planned |
| Kpessi | Hydraulic | 15.9 | Planned |
| Titira | Hydraulic | 23.8 | Planned |
| Sarakawa | Hydraulic | 24.2 | Planned |

| | | | |
|---|---|---|---|
| Wawa | Hydraulic | 8.4 | Planned |
| Baghan | Hydraulic | 5.8 | Planned |

*Table 6 : Decided/Planned projects for Togo*

### 3.2.2. Burkina Faso

Currently, Burkina Faso’s electric power generation capacity is mainly represented by generators using DDO or HFO, only 2MW of the capacity is supplied by hydroelectric power plants. The total available capacity is not high enough to ensure to load capacity of the country, Burkina Faso must import energy from Ivory-Coast (50MW).

| Name | Group | Combustible | Capacity [MW] |
|---|---|---|---|
| Ouaga I | Generator | DDO | 5 |
| OuagaII | Generator | HFO | 23.3 |
| Komsilga | Generator | HFO | 79.5 |
| Kossodo | Generator | HFO | 51 |
| Bobo II | Generator | HFO | 57 |
| Gaoua | Generator | DDO | 1.9 |
| Dedougou | Generator | DDO | 4.4 |
| Dori | Generator | DDO | 3 |
| Ouahigouya | Generator | DDO | 3.7 |
| NIORLA | Hydraulic | | 1.5 |
| TOURNI | Hydraulic | | 0.5 |

*Table 7 : Existing power capacity of Burkina Faso*

Burkina Faso’s projects have as fuel DDO and HFO, otherwise some hydraulics projects are planned to complete the production capacity.

| Name | Group | Capacity [MW] | Implementation |
|---|---|---|---|
| FADA | Generator | 7.5 | 2018 |
| KOSSODO | Generator | 50 | 2020 |
| Ouaga-Ouest | Generator | 100 | Planned |
| Ouaga-NordOuest | Generator | 70 | Planned |
| Samendeni | Hydraulic | 2.76 | 2019 |
| Bagré II | Hydraulic | 16 | Planned |
| Bontioli | Hydraulic | 5.1 | Planned |
| Gongourou | Hydraulic | 5 | Planned |
| Folonzo | Hydraulic | 10.8 | Planned |
| Ouéssa | Hydraulic | 21 | Planned |

*Table 8 : Decided/Planned projects for Burkina Faso*

### 3.2.3. Ivory Coast

Ivory Coast  is an exporting country, in 2018 it exports to Burkina Faso and Mali respectively 50MW and 70MW. The generation capacity has to ensure the local energy needs and the exports. Hydroelectric power plants represents, in 2018, 40% of the existing generation capacity, the other 60% are based on gas turbine and combined cycle.

| Name | Group | Combustible | Capacity [MW] |
|---|---|---|---|
| Azito | Combined cycle | GN | 152 |
| Azito | Combined cycle | GN | 152 |
| Azito | Combined cycle | GN | 168 |
| Ciprel | Gas turbine | GN | 33 |
| Ciprel | Gas turbine | GN | 33 |
| Ciprel | Gas turbine | GN | 33 |
| Ciprel | Gas turbine | GN | 111 |
| Ciprel | Combined cycle | GN | 111 |
| Ciprel | Combined cycle | GN | 117 |
| Ciprel | Combined cycle | GN | 111 |
| Vridi | Gas turbine | GN | 21.5 |
| Aggreko | Gas turbine | GN | 35 |
| Aggreko | Gas turbine | GN | 30 |
| Aggreko | Gas turbine | GN | 35 |
| Aggreko | Gas turbine | GN | 50 |
| Aggreko | Gas turbine | GN | 50 |
| Buyo | Hydraulic | | 54.9 |
| Buyo | Hydraulic | | 54.9 |
| Buyo | Hydraulic | | 54.9 |
| Kossou | Hydraulic | | 58.5 |
| Kossou | Hydraulic | | 58.5 |
| Kossou | Hydraulic | | 58.5 |
| Soubré | Hydraulic | | 93 |
| Soubré | Hydraulic | | 93 |
| Soubré | Hydraulic | | 93 |
| Taabo | Hydraulic | | 70.2 |
| Taabo | Hydraulic | | 70.2 |
| Taabo | Hydraulic | | 70.2 |

*Table 9 : Existing power capacity of Ivory Coast*

A lot of these power plants will be dismantled after the end of their life duration, Ivory-Coast has already decided the implementation year for some projects to compensate for ageing, moreover some projects are planned. The country wants to develop Coal power plant generation and to continue electricity production also with natural gas and hydroelectricity.

| Name | Group | Capacity [MW] | Implementation |
|---|---|---|---|
| Azito IV | Combined cycle | 180 | 2020 |
| Azito IV | Combined cycle | 100 | 2021 |
| Ciprel V | Combined cycle | 260 | 2020 |
| Ciprel V | Combined cycle | 130 | 2021 |
| Songon | Combined cycle | 3x123 | Planned |
| Abatta | Combined cycle | 3x123 | Planned |
| San Pedro I II III.IV | Coal power plant | 4x350 | Planned |
| Singrobo | Hydraulic | 44 | 2022 |
| Gribo Popoli | Hydraulic | 112 | 2022 |
| Boutoubre | Hydraulic | 150 | Planned |
| Louga | Hydraulic | 246 | Planned |
| Tayaboui | Hydraulic | 80 | Planned |
| Tiboto | Hydraulic | 113 | Planned |
| Tiassalé | Hydraulic | 51 | Planned |
| Daboitié | Hydraulic | 55 | Planned |
| Aboisso | Hydraulic | 90 | Planned |

*Table 10 : Decided/Planned projects for Ivory Coast*

### 3.2.4. Ghana

Ghana is known as an exporting country which exports to Benin and Togo, but it is also known as a country with a very obsolete nature of distribution equipment which generates a high level of losses in the distribution system.[11]

Ghana uses almost all of its hydroelectric potential, to ensure the electricity demand growth and exports. The electricity generation is also based on thermal capacity with gas turbines and combined cycles.

[11] (Center of Global Development, 2017)

| Name | Group | Combustible | Capacity [MW] | Implementation | Démantèlement |
|---|---|---|---|---|---|
| TAPCO | Combined cycle | DDO | 100 | 1997 | 2022 |
| TAPCO | Combined cycle | DDO | 100 | 1997 | 2022 |
| TAPCO | Combined cycle | DDO | 100 | 1998 | 2023 |
| TICO | Combined cycle | DDO | 100 | 2001 | 2026 |
| TICO | Combined cycle | DDO | 100 | 2001 | 2026 |
| TICO | Combined cycle | DDO | 100 | 2012 | 2037 |
| CENIT | Gas turbine | DDO | 100 | 2012 | 2037 |
| TT1PP | Gas turbine | DDO | 100 | 2009 | 2034 |
| TT2PP | Gas turbine | DDO | 11.7 | 2010 | 2035 |
| TT2PP | Gas turbine | DDO | 11.7 | 2010 | 2035 |
| TT2PP | Gas turbine | DDO | 7.2 | 2010 | 2035 |
| TT2PP | Gas turbine | DDO | 7.2 | 2010 | 2035 |
| TT2PP | Gas turbine | DDO | 7.2 | 2010 | 2035 |
| KTPP1 | Combined cycle | DDO | 100 | 2017 | 2042 |
| KTPP2 | Combined cycle | DDO | 100 | 2017 | 2042 |
| AKSA | Gas turbine | HFO | 345 | 2017 | 2042 |
| KARPOWER III | Gas turbine | HFO | 646 | 2018 | 2043 |
| AMERI | Gas turbine | NG | 230 | 2016 | 2041 |
| SUNSON ASOGLI | Combined cycle | NG | 180 | 2010 | 2035 |
| SUNSON ASOGLI | Combined cycle | NG | 340 | 2016 | 2041 |
| Akosombo | Hydraulic | | 150 | 2006 | 2056 |
| Akosombo | Hydraulic | | 150 | 2006 | 2056 |
| Akosombo | Hydraulic | | 150 | 2006 | 2056 |
| Akosombo | Hydraulic | | 150 | 2006 | 2056 |
| Akosombo | Hydraulic | | 150 | 2006 | 2056 |
| Akosombo | Hydraulic | | 150 | 2006 | 2056 |
| Bui | Hydraulic | | 114 | 2013 | 2063 |
| Bui | Hydraulic | | 114 | 2013 | 2063 |
| Bui | Hydraulic | | 114 | 2013 | 2063 |
| Kpong | Hydraulic | | 36 | 1982 | 2032 |
| Kpong | Hydraulic | | 36 | 1982 | 2032 |
| Kpong | Hydraulic | | 36 | 1982 | 2032 |
| Kpong | Hydraulic | | 36 | 1982 | 2032 |

*Table 11 : Existing power capacity of Ghana*

A large part of the power plant has been sized to compensate the obsolete level of the distribution network, few projects are decided or planned, to encourage initiatives to improve the distribution network.

| Name | Group | Capacity [MW] | Implementation |
|---|---|---|---|
| KPONT | Combined cycle | 120 | 2018 |
| CENPOWER | Combined cycle | 360 | 2018 |
| ATUABO | Coal power plant | 700 | Planned |
| CENIT ENERGY VRA | Combined cycle | 110 | Planned |
| Marinos | Combined cycle | 100 | Planned |
| Juale | Hydraulic | 87 | Planned |
| Pwalugu | Hydraulic | 48 | Planned |
| Daboya | Hydraulic | 43 | Planned |
| Hemang | Hydraulic | 93 | Planned |
| Kulpawn | Hydraulic | 36 | Planned |

*Table 12 : Decided/Planned projects for Ghana*

### 3.2.5. Niger

The generation capacity of the Niger is composed of small thermal power plants lower than 20MW. Its global size is about 151.4MW. Main fuels are DDO and coal, but Niger is also an importing country with an interconnection with Nigeria, it imports 40MW in 2018.

| Name | Group | Combustible | Capacity [MW] | Implementation | Démantèlement |
|---|---|---|---|---|---|
| GOUDEL | Generator | DDO | 12.6 | 2009 | 2039 |
| GAYA | Generator | DDO | 0.2 | 1998 | 2028 |
| GAYA | Generator | DDO | 0.42 | 2011 | 2041 |
| MARADI | Generator | DDO | 0.7 | 1989 | 2019 |
| MARADI | Generator | DDO | 1.2 | 2009 | 2039 |
| MARADI | Generator | DDO | 3.4 | 2009 | 2039 |
| TAHOUA | Generator | DDO | 1.5 | 1991 | 2021 |
| TAHOUA | Generator | DDO | 0.8 | 2009 | 2039 |
| MALBAZA | Generator | DDO | 0.75 | 1999 | 2029 |
| MALBAZA | Generator | DDO | 6 | 2015 | 2045 |
| ZINDER | Generator | DDO | 2.6 | 1991 | 2021 |
| ZINDER | Generator | DDO | 3.2 | 2009 | 2039 |
| AGADEZ | Generator | DDO | 1.4 | 2012 | 2042 |
| DIFFA | Generator | DDO | 6.664 | 2015 | 2045 |
| GOROUBANDA | Generator | DDO | 20 | 2016 | 2046 |
| GOROUBANDA | Generator | DDO | 20 | 2016 | 2046 |
| GOROUBANDA | Generator | DDO | 20 | 2016 | 2046 |
| GOROUBANDA | Coal power plant | Coal | 20 | 2016 | 2046 |
| AGGREKO | Generator | DDO | 10 | 2012 | 2042 |
| AGGREKO | Generator | DDO | 10 | 2012 | 2042 |
| AGGREKO | Generator | DDO | 10 | 2012 | 2042 |

*Table 13 : Existing power capacity of Niger*

Projects are planned with multiples phases as the coal power plant project Salkadamna with 2 phases. To complete the generation capacity, Niger plans to install 3 local hydroelectricity power plants.

| Name | Group | Capacity [MW] | Implementation |
|---|---|---|---|
| SONICHAR | Coal power plant | 68.8 | 2018 |
| GOROUBANDA 2 | Generator | 20 | 2020 |
| Diesel Nord | Generator | 4.5 | 2018 |
| SALKADAMNA ph1 | Coal power plant | 4x50 | 2022 |
| SONICHAR 2 | Coal power plant | 50 | Planned |
| SALKADAMNA ph2 | Coal power plant | 400 | Planned |
| Kandadji | Hydraulic | 130 | Planned |
| Gambou | Hydraulic | 105 | Planned |
| Dyodyonga | Hydraulic | 26 | Planned |

*Table 14 : Decided/Planned projects for Niger*

### 3.2.6. Nigeria

Nigeria is the more powerful country in the region with a huge natural gas potential. The Nigerian power plant is mainly composed of combined cycles, and gas turbine. It has exported to Niger, Benin and Togo in 2018. A lot of power plants will be dismantled during the study duration, because of the end of their life cycle. To compensate these power plant dismantlement, Nigeria has planned abundant projects decided or not which are listed in the appendix. For optimisation they will be modelized as candidate power plant.

| Name | Group | Combustible | Capacity [MW] | Implementation | Déclassement |
|---|---|---|---|---|---|
| DELTA | Gas turbine | GN | 511 | 2005 | 2030 |
| GEREGU GAS | Gas turbine | GN | 414 | 2013 | 2038 |
| OMOTOSHO GAS | Gas turbine | GN | 335 | 2007 | 2032 |
| OLORUNSOGO GAS | Gas turbine | GN | 293 | 2007 | 2032 |
| GEREGU NIPP | Gas turbine | GN | 444 | 2013 | 2038 |
| SAPELE NIPP | Gas turbine | GN | 113 | 2011 | 2036 |
| ALAOJI NIPP | Gas turbine | GN | 240 | 2013 | 2038 |
| OLORUNSOGO NIPP | Gas turbine | GN | 631 | 2012 | 2037 |
| OMOTOSHO NIPP | Gas turbine | GN | 505 | 2012 | 2037 |
| ODUKPANI NIPP | Gas turbine | GN | 113 | 2015 | 2040 |
| IHOVBOR NIPP | Gas turbine | GN | 339 | 2014 | 2039 |
| OKPAI | Gas turbine | GN | 450 | 2005 | 2030 |
| AFAM VI | Gas turbine | GN | 650 | 2005 | 2030 |
| IBOM POWER | Gas turbine | GN | 154 | 2009 | 2034 |
| AES EBUTE BARGE | Gas turbine | GN | 279 | 2002 | 2027 |
| OMOKU | Gas turbine | GN | 75 | 2006 | 2031 |
| TRANS AMADI | Gas turbine | GN | 75 | 2010 | 2035 |
| RIVERS IPP | Gas turbine | GN | 160 | 2012 | 2037 |
| GBARAIN | Gas turbine | GN | 113 | 2016 | 2041 |
| PARAS ENERGY | Gas turbine | GN | 52 | 2008 | 2033 |
| EGBIN | Gas turbine | GN | 880 | 1987 | 2022 |
| SAPELE | Gas turbine | GN | 528 | 1990 | 2025 |
| KAINJI | Hydraulic | | 160 | 1978 | 2028 |
| KAINJI | Hydraulic | | 100 | 1976 | 2026 |
| JEBBA | Hydraulic | | 506 | 1988 | 2038 |

| | | | | | |
|---|---|---|---|---|---|
| SHIRORO | Hydraulic | | 450 | 1990 | 2040 |

*Table 15 : Existing power capacity of Nigeria*

| Name | Group | Capacity [MW] | Implementation |
|---|---|---|---|
| GBARAIN/UBIE I | Gas turbine | 113 | 2018 |
| EGBEMA I -NIPP | Gas turbine | 113 | 2018 |
| OMOKU - NIPP | Gas turbine | 113 | 2018 |
| ALAOJI 2 - NIPP | Gas turbine | 285 | 2025 |
| EGBEMA I -NIPP | Gas turbine | 113 | 2019 |
| EGBEMA I -NIPP | Gas turbine | 113 | 2019 |
| KADUNA IPP | Gas turbine | 215 | 2019 |
| OMOKU - NIPP | Gas turbine | 113 | 2019 |
| Mambila | Hydraulic | 3050 | Planned |
| Zungeru | Hydraulic | 700 | Planned |
| Gurara | Hydraulic | 30 | 2018 |
| Mabon | Hydraulic | 39 | Planned |
| Kashimbilla | Hydraulic | 40 | Planned |

*Table 16 : Decided projects and Hydroelectricity projects (Thermal planned projects are in the appendices)*

### 3.2.7. Additional economic data

In this subsection are presented electric power exchanges between countries, costs of these exchanges, fuel prices, interest rates and candidate power plants with all their characteristics.

Interconnections will be maintained for the self-sufficient strategy, exchanges will be cancelled or increased according to the country needs. Table 17 : Bilateral agreements in the Eastern Zone suggests that imports could increase because the line capacity is not fully used.

| Interconnection From - To | Line capacity [MVA] | Line capacity [MW] | Exchange capacity [MW] |
|---|---|---|---|
| Nigeria - Benin | 388.5 | 311 | 100 |
| Nigeria - Niger | 189.7 | 152 | 40 |
| Nigeria - Togo | 388.5 | 311 | 100 |
| Ghana - Benin | 128 | 102 | 25 |
| Ghana - Togo | 128 | 102 | 25 |
| Ivory Coast - Burkina Faso | 327 | 262 | 50 |
| Ivory Coast - Mali | 327 | 262 | 70 |

*Table 17 : Bilateral agreements in the Eastern Zone*

Export prices, fuel prices are depending on political negotiations which are confidential, nevertheless it is possible to make some hypothesis :

- Export costs are based on a study from 2001, due to the lack of information.[12]

| Exchange costs [$/MWh] | Benin | Burkina Faso | Mali | Niger | Togo |
|---|---|---|---|---|---|
| Nigeria | 67 | | | 63 | 67 |
| Ghana | 69 | | | | 69 |
| Ivory Coast | | 63 | 63 | | |

*Table 18 : Exchanges costs in the Eastern Zone of ECOWAS*

- The cost of liquid fuels and coal depends on whether the country is coastal or not.
- Natural gas (NG) price depends on whether is from local production or importation form the West African Gas pipeline (WAG) or from liquefied gas (NGL).

| Fuel | USD/GJ | USD/Gcal |
|---|---|---|
| NG local | 5.1 | 21.35268 |
| GN WAG | 6.9 | 28.88892 |
| GN NGL | 6.9 | 28.88892 |
| HFO coastal | 9 | 37.6812 |
| DDO coastal | 13.3 | 55.68444 |
| Coastal Coal | 4.3 | 18.00324 |

| Type de combustible | USD/GJ | USD/Gcal |
|---|---|---|
| HFO land-based | 11.5 | 48.1482 |
| DDO land-based | 15.6 | 65.31408 |
| LCO land-based | 12.8 | 53.59104 |
| Land-based Coal | 2.8 | 11.72304 |

*Table 19 : Fuel prices*

These prices are not an absolute fact, they can represent the context and will be constant during this study.

The situation of ECOWAS member countries is different for everyone. Risk aversion to investing is more or less high, which is why it is important to work with different interest rates that characterize everyone's situation. The rates are defined according to the risk assessment and the business environment in the country. These criteria are noted by letters A, B, C, D, according to a study (COFACE, 2018). For this work, rate values were assigned and then an average is made with the rates corresponding respectively to the risk assessment rating and the business environment rating.

The business environment is based on economic aspects of the country and thus its strengths and weakness. On the other hand, the risk aversion is based on internal and external political and social aspects. This is how we have obtained these different interest rates for the Eastern zone.

| Country | Risk aversion | Interest rate | Business environment | Interest rate | **Final interest rate** |
|---|---|---|---|---|---|
| Benin | B | 0.06 | C | 0.08 | **7%** |
| Burkina Faso | C | 0.08 | C | 0.08 | **8%** |
| Ivory Coast | B | 0.06 | B | 0.06 | **6%** |
| Ghana | B | 0.06 | B | 0.06 | **6%** |
| Niger | C | 0.08 | C | 0.08 | **8%** |
| Nigeria | C | 0.08 | D | 0.1 | **9%** |
| Togo | C | 0.08 | C | 0.08 | **8%** |

*Table 20 : Interest rate in the Eastern Zone of ECOWAS*

To represent planned projects, a list presents all candidate power plants with their characteristics needed for the expansion planning.

[12] (Ndour, 2001) These values, which date back to 2001, should have been reduced to 2018 with an inflation rate of 2.12% (CPI Inflation calculator, 2018)

| Name | Capacity [MW] | Efficiency [%] | Spe.cons [kCal/kWh] | Investment [$/kW] | Life cycle | Fixed O&M [$/kW/mois] | Variable O&M [USD/MWh] | Breakdown rate [%] | Maintenance rate [J/an] | CO2 emission [tCO2/TEP] |
|---|---|---|---|---|---|---|---|---|---|---|
| CC1 | 300 | 0.49 | 1755.96 | 996 | 25 | 0.55 | 3.765 | 0.082 | 29.93 | 5.19 |
| CC2 | 300 | 0.51 | 1687.10 | 866 | 25 | 0.52 | 3.51 | 0.082 | 29.93 | 5.19 |
| CC3 | 450 | 0.495 | 1738.22 | 937 | 25 | 0.52 | 3.519 | 0.082 | 29.93 | 4.47 |
| CC4 | 450 | 0.52 | 1654.66 | 799 | 25 | 0.48 | 3.281 | 0.082 | 29.93 | 4.47 |
| CC5 | 60 | 0.49 | 1755.96 | 1516 | 25 | 3.32 | 6.98 | 0.082 | 29.93 | 4.26 |
| CC6 | 60 | 0.515 | 1670.72 | 1484 | 25 | 3.10 | 6.51 | 0.082 | 29.93 | 5.62 |
| OCGT7 | 45 | 0.315 | 2731.50 | 890 | 25 | 1.45 | 4.68 | 0.075 | 27.38 | 7.75 |
| OCGT8 | 100 | 0.33 | 2607.34 | 606 | 25 | 1.36 | 4.38 | 0.075 | 27.38 | 7.21 |
| OCGT9 | 150 | 0.34 | 2530.65 | 567 | 25 | 1.27 | 4.09 | 0.075 | 27.38 | 6.67 |
| COAL10 | 125 | 0.35 | 2458.35 | 1652 | 35 | 2.64 | 5.3 | 0.105 | 38.33 | 9.86 |
| COAL11 | 250 | 0.37 | 2325.46 | 1622 | 35 | 2.29 | 4.6 | 0.102 | 37.23 | 9.58 |
| HFO1 | 10 | 0.4 | 2151.05 | 1450 | 20 | 1.40 | 7.1 | 0.07 | 25.55 | 8.29 |
| HFO2 | 20 | 0.4 | 2151.05 | 1350 | 20 | 1.40 | 7.1 | 0.07 | 25.55 | 8.29 |
| DDO1 | 10 | 0.36 | 2390.06 | 1070 | 20 | 0.70 | 10.1 | 0.07 | 25.55 | 8.62 |
| NGCC | 702 | N/A | 1666.67 | 600.6 | N/A | 0.31 | 2.1 | N/A | N/A | N/A |
| ANGCC | 429 | N/A | 1590.91 | 1104 | N/A | 0.83 | 2 | N/A | N/A | N/A |
| CT-GT | 100 | N/A | 2525.25 | 1101 | N/A | 1.46 | 3.5 | N/A | N/A | N/A |
| ACT-GT | 237 | N/A | 2474.75 | 678 | N/A | 0.57 | 10.7 | N/A | N/A | N/A |
| USC | 650 | 0.46 | 2222.22 | 3636 | N/A | 3.51 | 4.6 | N/A | N/A | N/A |
| CTNG | 300 | N/A | 2601 | 226 | N/A | 1.83 | 1.3 | N/A | N/A | N/A |
| PCG | 300 | N/A | 2262.6 | 4620 | N/A | 4.25 | 5 | N/A | N/A | N/A |
| HYD | - | - | - | - | 50 | 8.33 | 2 | 0.05 | 23.75 | - |

*Table 21 : Candidate power plants[13]*

Other power plants have been studied (SIEMENS[14] or GE Power[15]) but there was a lack of information on O&M costs and other characteristics, this is the reason why this study is done with candidate power plants from the Table 21. The Table 22 : Acronyms signification

, presents the name given to every candidate power plants :

[13] (U.S. Energy Information Administration, 2016)
[14] (Siemens, 2018)
[15] (GE Power, 2018)

| Appellation | Signification | Fueln°1 | Fueln°2 |
|---|---|---|---|
| CC | Combined cycle | Natural gas | Few liquid fuels |
| OCGT | Gas turbine | Natural gas | Few liquid fuels |
| COAL | Coal power plant | Coal | - |
| HFO | Generator | Heavy fuel | Few liquid fuels |
| DDO | Generator | Ordinary diesel | Few liquid fuels |
| ANGCC | Advanced Combined cycle | Natural gas | Few liquid fuels |
| ACT-GT | Advanced Gas turbine | Natural gas | Few liquid fuels |
| USC | Ultra Supercritical Coal | Coal | - |
| CTNG | Pulverized Coal | Coal | - |
| PCG | Pulverized Coal Greenfield | Coal | - |
| HYD | Hydraulic power plant | Water | - |

*Table 22 : Acronyms signification*

### 3.2.8 Presentation of different technologies used

- Coal power plant : Coal power plants produce electricity by using the heat generated by the combustion of coal. After being sorted and washed, the coal is burned in a boiler, the heat generated heats the water and vaporizes it, the steam drives a turbine which, combined with an alternator, generates electricity. There are two methods to supply the thermal power plant:

    - The coal is crushed into small pieces to reduce it to fine dust for fuel. The energy efficiency of this process depends very much on the quality of the coal used.
    - Coal can be crushed and leads to the formation of a layer maintained in suspension by vertical air injection. Coal particles burn suspended and partially burned dust is recovered and re-injected into the boiler. This technic has the advantages of high efficiency, being able to use the bad qualities of coal and being low polluting.

New technologies could improve efficiencies while protecting the environment, including $CO^2$ capture and storage and ultra-supercritical power plants with an efficiency of 46%.[16]

- Hydraulic power plant : Hydraulic power generation exploits the potential energy of watercourses. Different techniques can be selected according to the geographical characteristics of the sites and are used to exploit this energy.

    - Lake power plants are associated with a water retention created by a dam. Water is collected in the upstream watersheds and stored behind the dam. This type of power plant is capable of supplying large quantities of energy very quickly, often called during high consumption and peak periods.
    - Run-of-river power plants do not have a reservoir and provide so-called basic energy produced in the run-of-river. This type of power plant requires only a few line constructions because its use is local, for a constant and reliable basic production.[17]

[16] (BP, 2016)
[17] (Syndicat des énergies renouvelables, 2012)

Hydropower plants depend on water supplies, in the dry season the available power will be low while during the rainy season the available power is close to the installed power. To remain as close as possible to reality, the minimum energy provided in the year by a hydropower plant is equal to 75% of the average energy. To obtain the available capacity for the average annual energy, a load factor of 0.40 is applied to the installed capacity for run-of-river and storage power plants.[18]

- Generators[19]: This device allows the production of electricity, by supplying it with fuel. This technology is able to compensate for any network shortcomings. They are composed of an internal combustion engine and an alternator. The internal combustion engine works in combustion, the reaction transforms the energy supplied by the fuel (heavy fuel oil or ordinary diesel) into mechanical energy that activates the alternator. The alternator once in operation provides electrical energy. They have three main functions:

    - They can be used in case of emergency, during a power failure, they start automatically and provide the necessary energy in the present time. They are generally present in public services, financial services in which a power outage can have terrible consequences.
    - They can also be considered as the main supply of electricity, by operating continuously.
    - The third possible function of these generators is to complete the electricity supply of the network during peak hours. They are automatically switched on to meet energy demand that may exceed production capacity.

- Gas turbine[20]: Gas turbine engines derive their capacity from the combustion of fuel in a combustion chamber and the use of combustion gases to drive a turbine in the same way that high-pressure steam drives a steam turbine. A gas turbine consumes a lot of energy just to drive its compressor. As with all cyclic combustion engines, a higher maximum operating temperature in the machine means greater efficiency (Carnot's law), but in a turbine, it also means that more energy is lost in the form of heat. As a result, the efficiencies of single cycle turbines are quite low. One advantage of gas turbines is their fuel flexibility. They can be adapted to use almost all flammable petroleum products based on flammable gases or light distillates such as gasoline, diesel and kerosene that are available locally, although natural gas is the most commonly used fuel. Crude oils and other heavy oils can also be used. Gas turbines can be used for large-scale power generation. These facilities are not normally used for baseload power generation, but are used in large power systems for peak-shaving applications to provide peak power in an emergency.

- Combined cycle[21]: Combined cycle uses natural gas as a primary energy source. A combined cycle combines two types of power plants: the gas turbine, also known as a combustion turbine, and the steam turbine. Each one leads to the production of electricity. The gas turbine produces electricity from combustion gases. The fumes produced by this combustion can be hot enough to generate steam that drives the steam turbine. The combination of these 2 cycles allows to draw more work from the heat produced by a combustion. They can achieve a motor efficiency

[18] (Realistic Energy, s.d.)
[19] (Colin, 1998)
[20] (Electropaedia, 2005)
[21] (Electricité de France, 2013)

of 60%. $CO_2$ emissions are reduced by half compared to other thermal production methods. As with gas turbines alone, combined cycles can use a variety of liquid fuels.

For the same candidate power plant, investment costs vary from one country to another because of the different interest rates applied. To obtain these different investment costs, the corresponding annuities must be calculated by summing them over the lifetime of the power plants and then dividing by the sum of the updates. This calculation is done for the single market strategy, which will allow you to choose where it is more interesting to invest in power plants.

With this global presentation of the data, it is possible to apply the method of carrying out expansion plans to the different strategies.

# 4. Self-sufficient strategy : analysis and results

The PlanElec software is used for the application of the method for carrying out expansion plans. In this section, the evolution of the existing and installed base of each country will be presented, while respecting the decommissioning of the plants, using projects and imports. The results will be presented in summary tables for each country. A review of total investment in the sub-region and weighted production costs will be carried out in order to compare the results with the Single Market strategy.
Here is a description of the approach adopted to size a power plant for each country:

The equilibrium time method allows pre-dimensioning for energy planning. In this study, it is applied to add to the existing fixed system and the decided projects, the candidate thermal power plants chosen for each country.

## 4.1. Import countries in the Eastern Zone of the ECOWAS

The importing countries in the eastern zone of the ECOWAS are Benin, Togo, Burkina Faso and Niger in 2018. These countries import electricity to support local production and ensure the demand.

There is an important point concerning Benin and Togo to report:

The CEB, which is the international organization for the production and transmission of electricity in Benin and Togo, has 3 power plants currently in operation: the gas turbines of Lomé Port and Maria Gleta, each with 24 MW and the Nangbeto Dam with 2x32.5 MW. There is a business model proposed by the CEB on the distribution of the energy produced:

- When there is no limitation - that is, when the plants are able to provide what is necessary for both countries - the distribution is as follows: 55% for Benin and 45% for Togo.
- When there is a limitation, so that Benin and Togo cannot use it as they wish, the distribution is made with 53% and 47% respectively for Benin and Togo.

The evolution of the generating power plant of importing countries is summarized in Table 32, shown by histograms (Figure 4, Figure 5, Figure 6 & Figure 7) and appended histograms summarizing energy production by plant type (Figure 31, Figure 32, Figure 33 & Figure 34).

- Benin has a levelized cost of energy of $0.092/kWh, imports from Nigeria are increasing. Hydraulic projects are all carried out, however, the resulting production is low with only 7.4% of the energy produced for 22% of the total installed capacity.
- Togo has a lower levelized cost of energy than Benin despite their very strong link (0.080$/kWh), this is mainly due to the fact that Togo uses natural gas more than heavy fuel oil unlike Benin. Togo's hydraulic capacity is better able to supply energy than Togo's because with

less installed capacity, it provides 10% of the energy needed to meet demand, which remains low despite everything.

- Burkina Faso's levelized cost of energy is the highest in the eastern region of ECOWAS: $0.118/kWh. The net present cost is also high. These two facts are due to the use of thermal power plants using heavy fuel oils such as DDO and HFO. Moreover, the country's hydraulic potential is very low, only 2% of the production is ensured.
- Niger continues to import from Nigeria. Its levelized cost of energy is $0.074/kWh, mainly due to the use of local coal and natural gas from Nigeria.

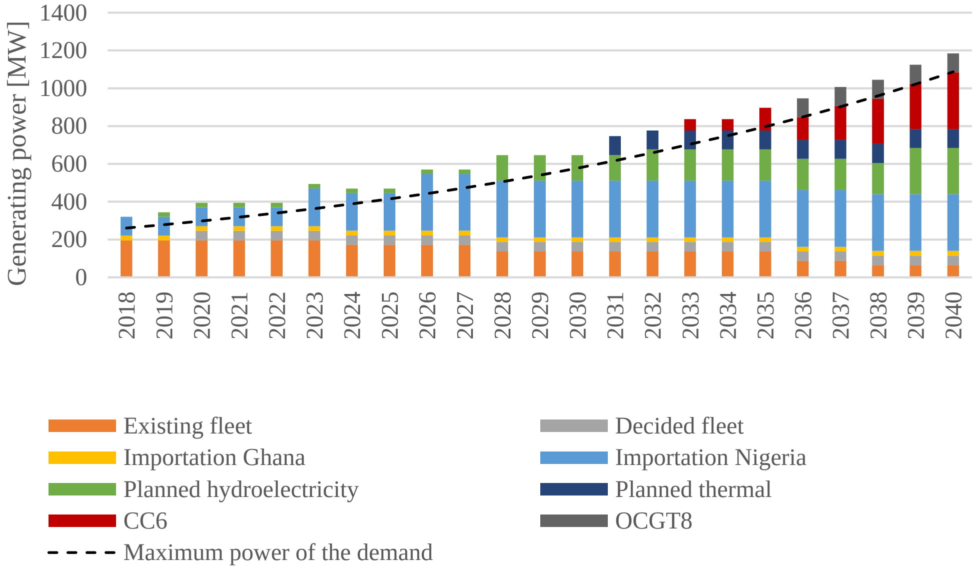


*Figure 4 : Evolution of the generating power of Benin*

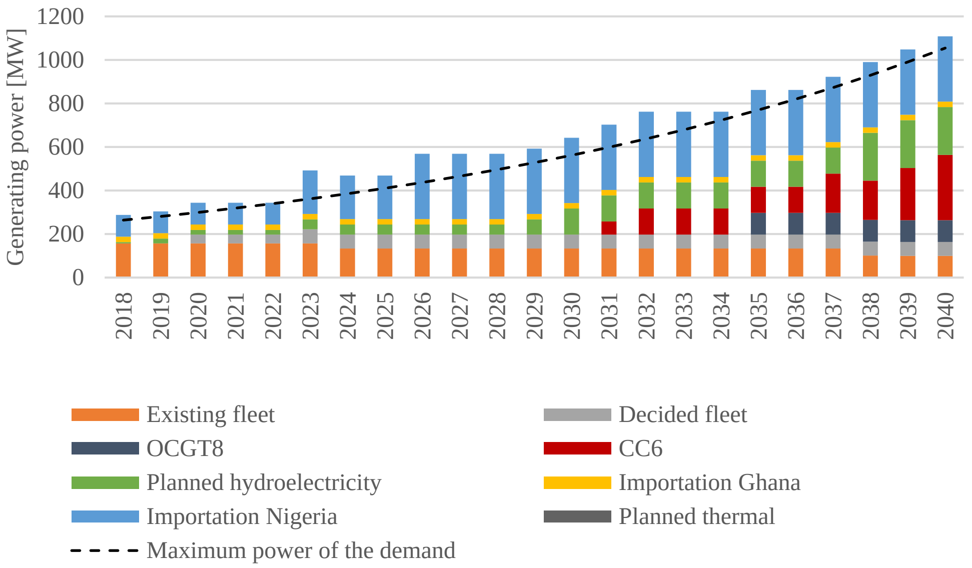


*Figure 5 : Evolution of the generating power of Togo*

Imports for Benin and Togo are equal over the entire study period. Most of Benin's thermal power plants use mainly ordinary diesel, while Togo's uses mainly natural gas, this difference in fossil fuels used and Togo's higher load factor lead to lower investment and levelized cost of energy for Togo. Nevertheless, the investment dynamics of these two countries are identical with the arrival of combined cycles and candidate gas turbines from the early 2030s and a growing hydroelectric fleet from 2018 to 2040 but which does not have the same production capacities as shown by the available energies of these two countries.

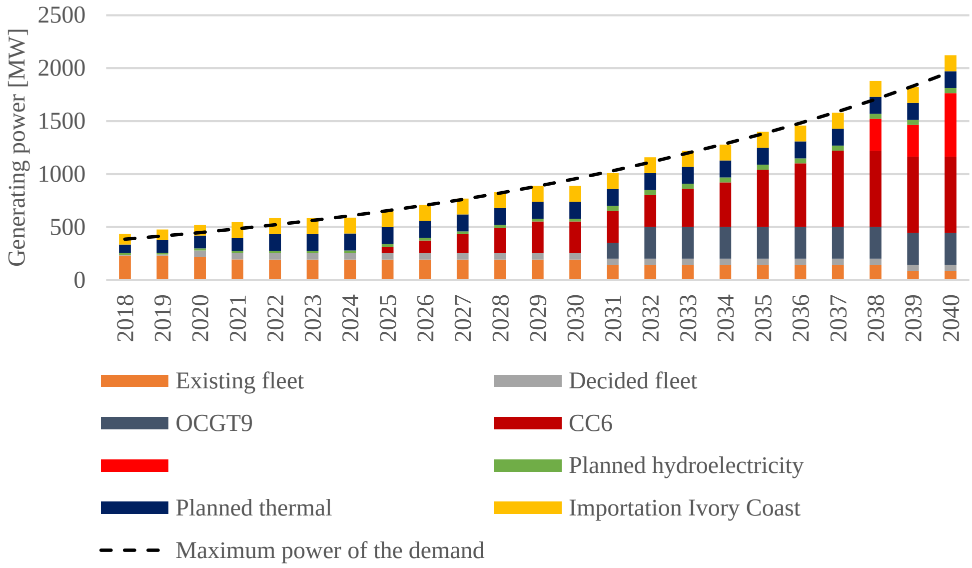


*Figure 6 : Evolution of the generating power of Burkina Faso*

Burkina Faso continues to produce its electricity using regular diesel and heavy fuel oil as its main fuels. Demand, as in all countries of the sub-region, is growing strongly between 2018 and 2040, and power plants must be installed to ensure this demand. Combined cycles and gas turbines are gradually being installed but keep hydrocarbon fuels as the main supply, which helps to keep the cost of electricity production high.

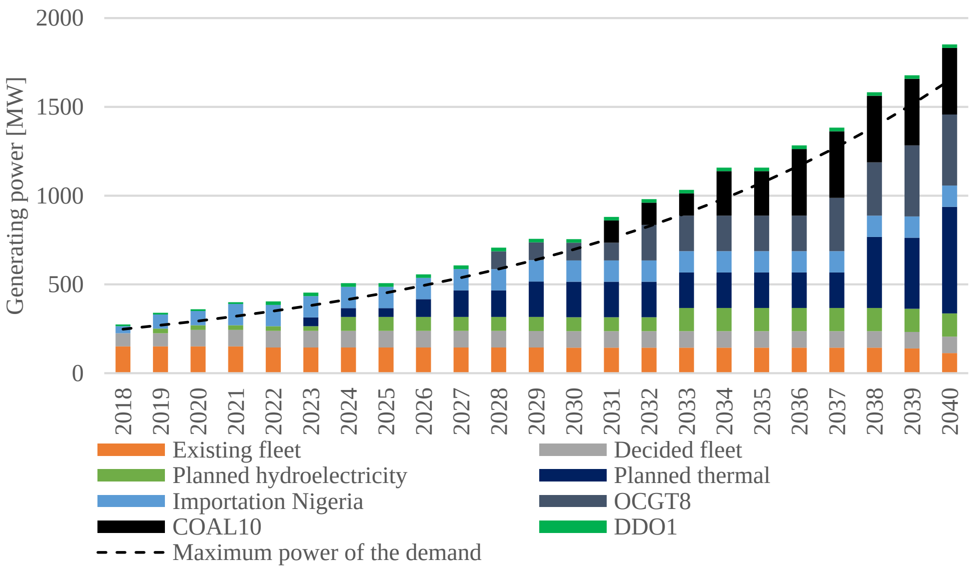


*Figure 7 : Evolution of the generating power of Niger*

As in Burkina Faso, the hydraulic potential is low for Niger. The difference is that Niger has a local coal potential on which it will rely with demand and create an energy mix with thermal power plants using natural gas imported from Nigeria as primary fuel. In addition to this import from primary sources, Niger imports electricity from Nigerian production.

In general, the levelized cost of energy remains quite high for importing countries.

### 4.2. Export countries in the Eastern zone of the ECOWAS

The exporting countries in the eastern zone of the ECOWAS in 2018 are: Nigeria, Ghana and Ivory Coast. The fleet to be installed corresponds to the fleet joining their national demand and exports during the study period. Existing interconnection lines were taken into account as well as exported capacities and it was envisaged that the capacity of the lines could be increased between 2018 and 2040.

As for importing countries, the functional fleet will be summarized in Table 33, precised by histograms (Figure 8, Figure 9 & Figure 10) and appended histograms summarizing energy production by plant type and its evolution specified in Appendix by histograms. (Figure 35, Figure 36 & Figure 37)

- In Ghana in 2018, installed capacity is 40% greater than demand power, but the transmission and distribution system is of poor quality. As almost all of the hydraulic potential is used, few hydraulic projects are added to the existing fleet. With Sankofa, local gas production is reserved for electricity production. Ghana then turned to a fleet of gas-fired thermal power plants such as combined cycle power plants and gas turbines. With its local gas and few hydropower plants, Ghana's levelized cost of energy remains relatively low for the region at $0.057/kWh.
- In Ivory Coast, with the evolution of the existing thermal fleet, the candidate projects are based on high-power combined cycles. As in Ghana, gas production is exclusively dedicated to electricity. Côte Ivoire's hydropower potential is very well exploited, investments in hydropower plants are not as high as in other countries and the amount of energy produced is more attractive than in other countries. As for Ghana, levelized cost of energy is relatively low at 0.055$/kWh.
- Nigeria is a major producer of natural gas, making this resource a priority and shifting its fleet to combined cycle and gas turbines. To meet its energy needs (76% of the energy demand in the East zone), the net present cost is very high. As the share of hydropower is very low (4% of the energy produced), the levelized cost of energy is higher than for Ghana and Ivory Coast. Faced with the country's current situation, represented by a high interest rate of 9%, Nigeria requires a lot of investment to meet its growing demand.

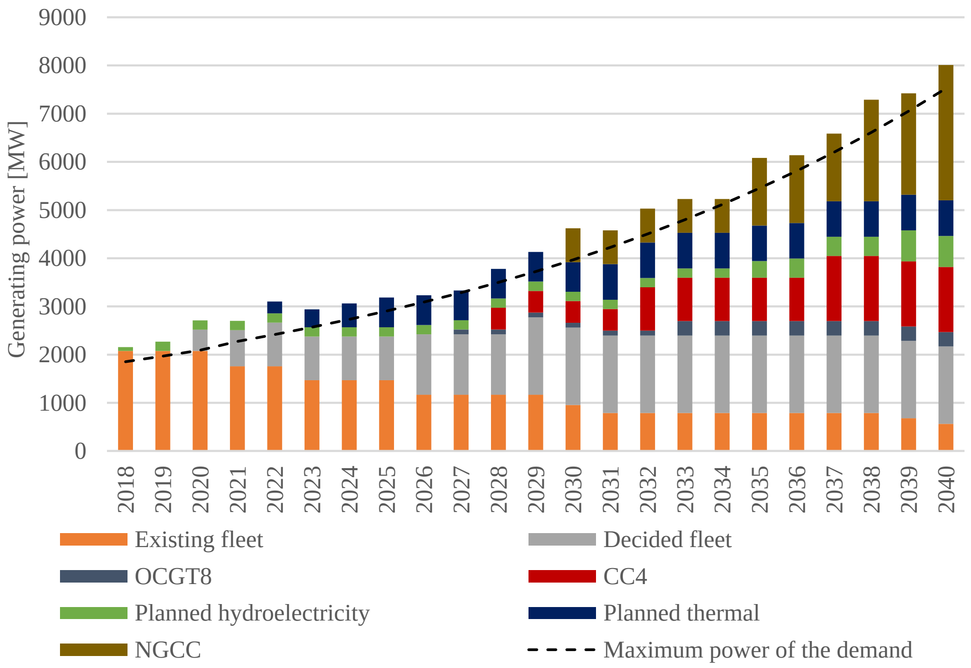


*Figure 8 : Evolution of the generating power of Ivory Coast*

With a policy that has decided to reserve gas production for electricity, combined cycle and gas turbine, projects are accumulating and ensuring the quality of supply in Ivory Coast. A few hydroelectric projects are being added to the park over the years.

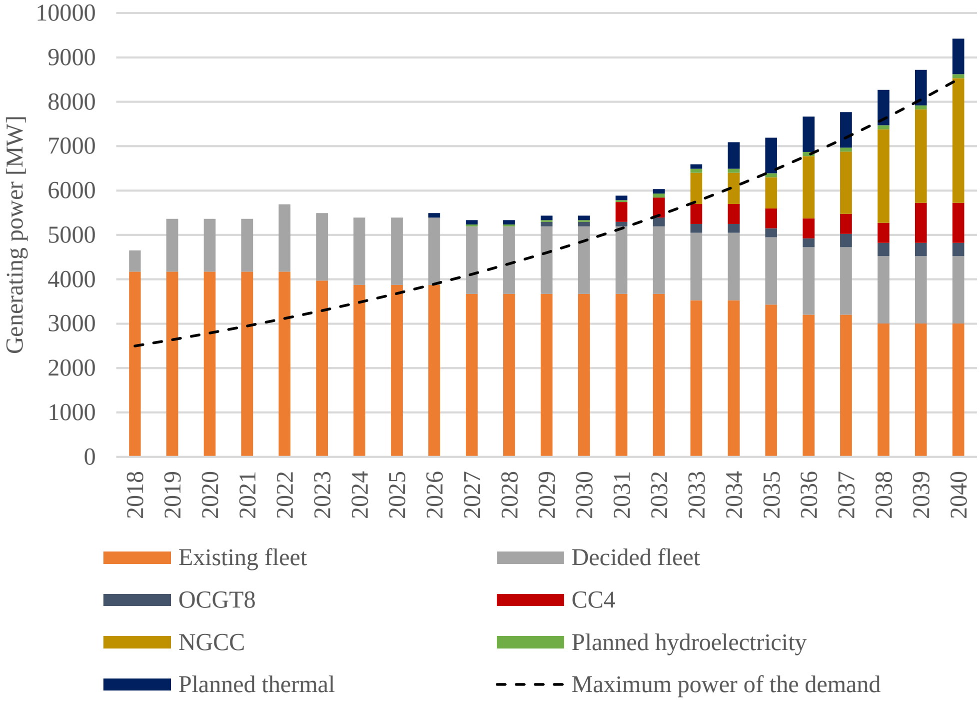


*Figure 9 : Evolution of the generating power of Ghana*

During the past years, following a supply crisis during which Ghana no longer received gas to produce its electricity, it has used large diesel power plants powered by ordinary diesel or heavy fuel oil. In addition, Ghana's distribution and transport system is considered to be in an obsolete state on which there is a lot of energy loss. So with an oversized fleet due to this poor quality of the distribution and transmission network, Ghana finds itself with a power of the fleet higher than the power of demand.

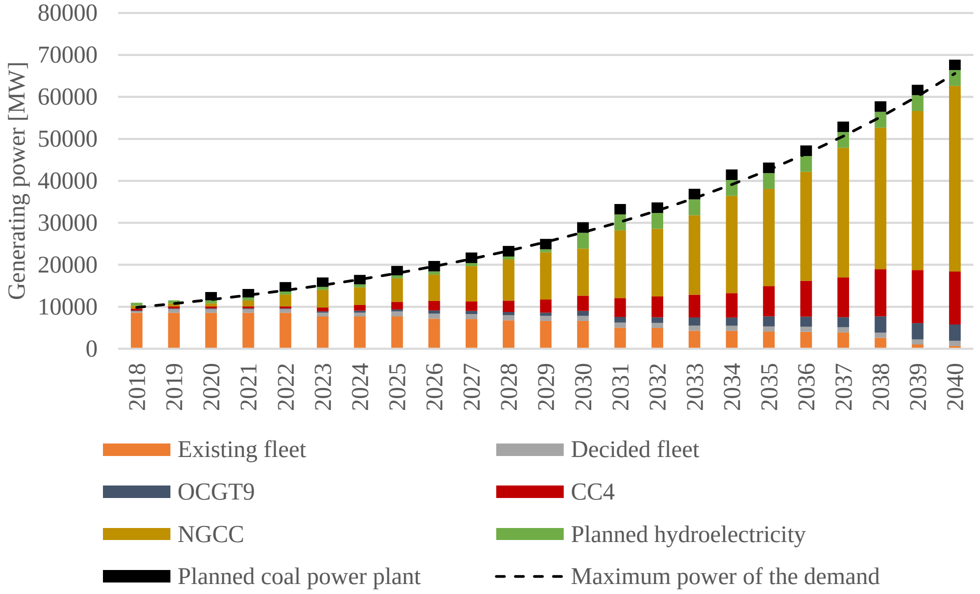


*Figure 10 : Evolution of the generating power of Nigeria*

Nigeria's demand between 2018 and 2040 explodes, and the capacity of the lines between Benin-Togo and Niger have increased, so it is necessary to ensure production and quality of service for all this population. Major investments are to be made, particularly in thermal power plants with the intensive use of natural gas. As can be seen in Figure 10, the installed hydroelectric capacity is very small compared to other plants. The possibility of installing coal power plants was not successful given the country's enormous natural gas potential.

## 4.3. Representation of the power plant situation in the ECOWAS Eastern zone

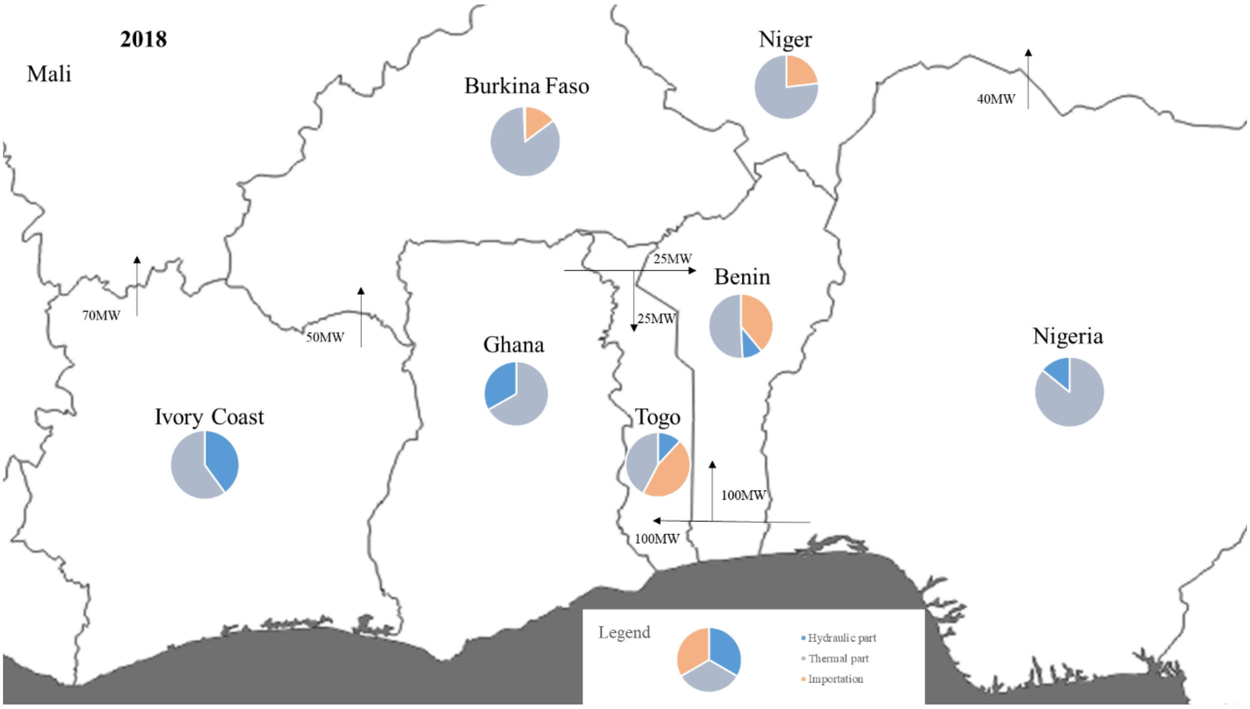


*Figure 11 : Power plant part installed in 2018 in the ECOWAS Eastern zone*

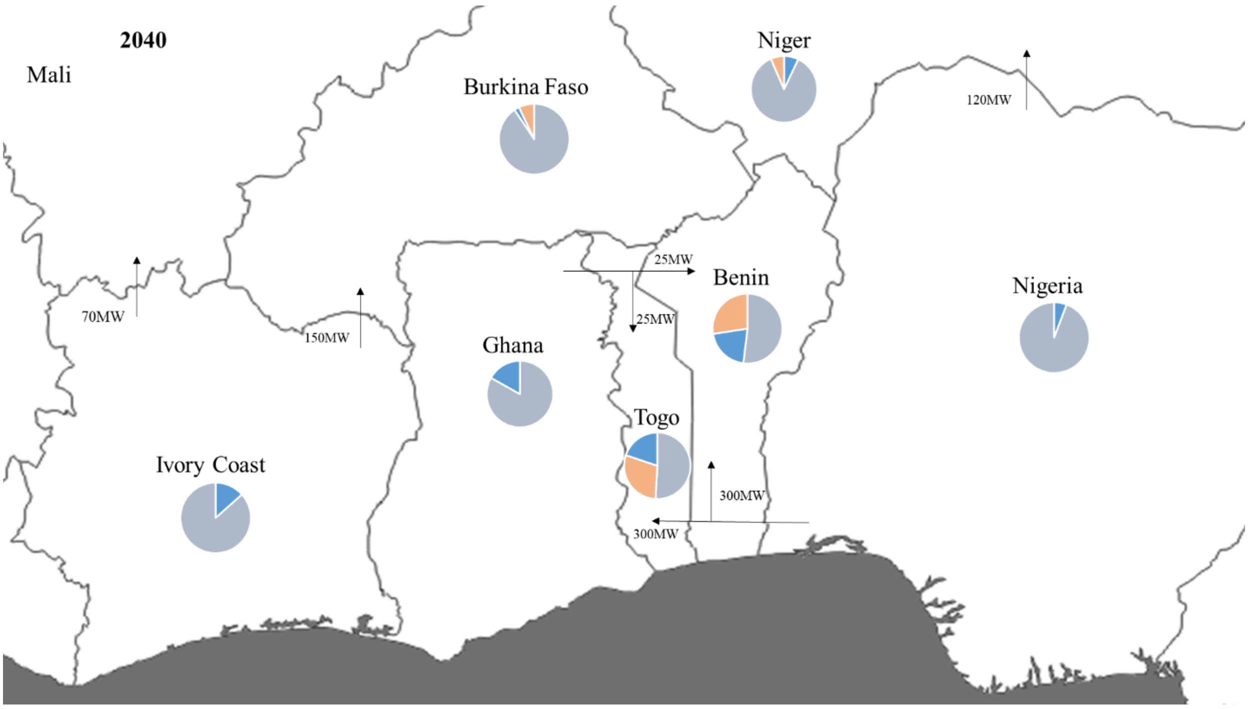


*Figure 12 : Power plant part installed in 2040 in the ECOWAS Eastern zone*

In Figure 11, in 2018, for most importing countries, the majority of electricity supply depends on thermal power plants and imports from Nigeria, Ghana or Ivory Coast. The hydraulic part of the production systems of the importing countries represents only a small part of the installed capacity. It is interesting to note that hydropower is well exploited in Ivory Coast and Ghana.

In Figure 12, in 2040, whether importing or exporting countries, the share of thermal energy is the largest. For importing countries, the import share decreases. For Ghana already in 2018, the hydraulic potential is exploited to the maximum with the evolution of demand and Sankofa's production, Ghana has turned to natural gas. For Ivory Coast, the share of installed hydropower capacity is decreasing because gas sources are reserved for electricity production, so Ivory Coast is moving towards gas-fired thermal power plants despite some hydropower projects. Nigeria is the major power in the sub-region, with an oil and gas well. It seems obvious that the country is turning to systems that use the resources available as a priority.

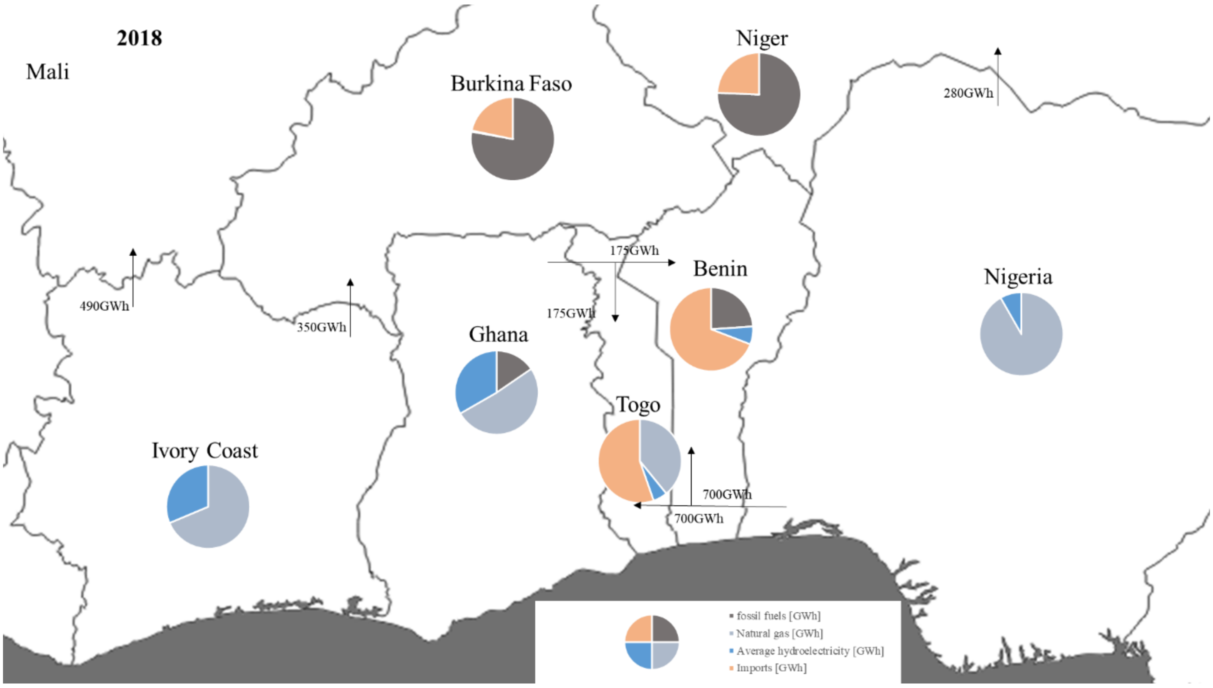

*Figure 13 : Part of produced energies in 2018 in the Eastern zone of the ECOWAS*

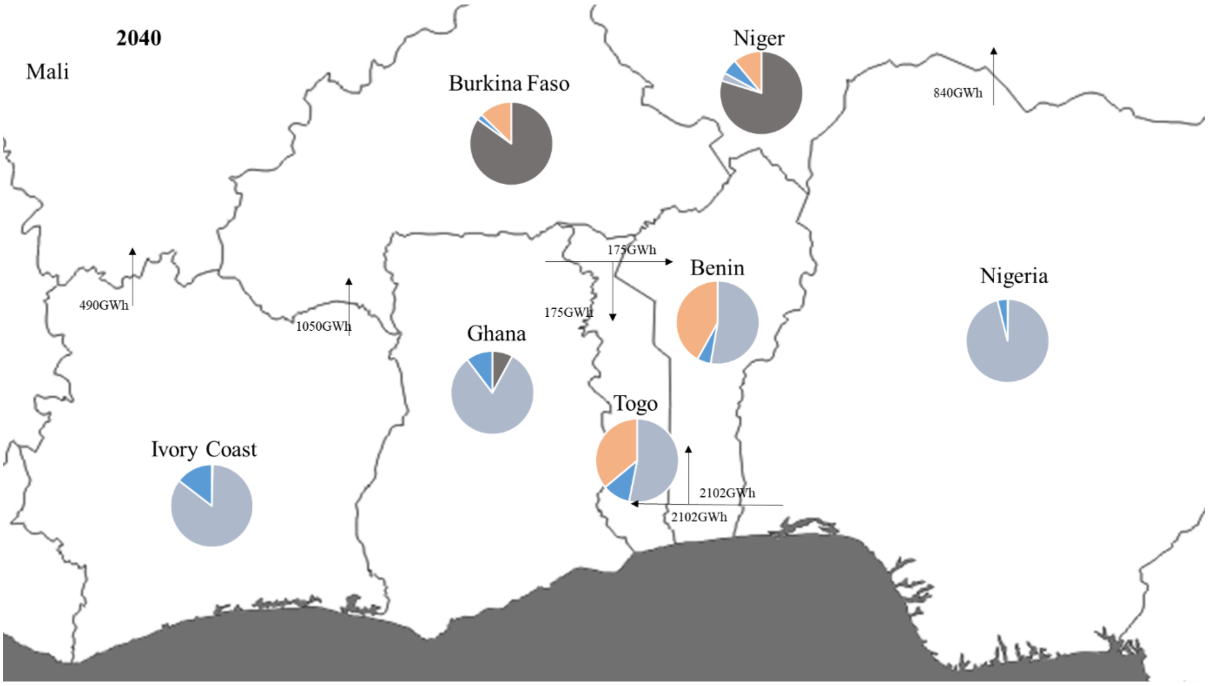


*Figure 14 : Part of produced energy in 2040 in the Eastern zone of the ECOWAS*

With Figure 13 and Figure 14, we can see that the energy produced by hydroelectric power plants can represent a large part of the energy produced, as for example for Ghana and Ivory Coast; but it can also be low despite the share of installed capacity, as for Benin and Togo. It is important to understand that for hydroelectricity the installed capacity is not the most important. The system is highly dependent on its location, hydrological conditions, water supply, weather and other factors. Indeed, in dry periods, the electrical energy from hydroelectricity is low and this, despite a large installed capacity. To operate at full power it is necessary to have sufficient water supplies. This is why for hydroelectric power plants we also speak of base power, minimum guaranteed energy, which corresponds to the energy produced guaranteed each year by the base power, and average annual energy, which is the energy produced on average each year, taking into account local conditions.

Within the eastern zone of ECOWAS, there are 3 countries with the capacity to export and 4 countries with the need to import. For this self-sufficient strategy, the supply of electricity depends heavily on natural gas from local production in export countries, which are able to meet their needs with their own resources. Import countries, despite some hydroelectric projects, which remain a technology highly dependent on climatic conditions, have mainly turned to thermal power plants: coal, HFO, DDO & natural gas. They are also subject to import to meet their needs.
In addition to natural gas and coal power plants, electricity production in the Eastern part of West Africa remains relatively expensive. With a levelized cost of energy ranging from \$0.055 to \$0.118/kWh, the price of electricity in the eastern zone depends on the country situation. This is why it is interesting to compare and project towards a single market that implies affordable electricity production for the whole population and better quality of service, which will be presented in the next section.

# 5. Single regional market strategy : analysis and results

The aim of the single market is to bring together the East and West zones into a single region. This project undertaken by ECOWAS aims to establish a power generation system that provides better quality of service at an affordable cost for all populations. This work is carried out in collaboration with the work of Mr Prioretti Luc who worked during the self-sufficient strategy on the countries of the Western zone.[22]

| Eastern Zone | Benin | Burkina Faso | Ivory Coast | Ghana | Niger | Nigeria | Togo |
|---|---|---|---|---|---|---|---|
| Total cost $M | 2629 | 3995 | 13220 | 16385 | 2527 | 75865 | 2443 |
| Levelized cost of energy [$/kWh] | 0.092 | 0.118 | 0.055 | 0.057 | 0.093 | 0.064 | 0.08 |

*Table 23 : Net present cost and Levelized cost of energy for the Eastern Zone of the ECOWAS*

| Western Zone | Gambia | Guinea | Guinea-Bissau | Liberia | Mali | Senegal | Sierra Leone |
|---|---|---|---|---|---|---|---|
| Total cost $M | 1378 | 6150 | 758 | 1041 | 3321 | 6322 | 2033 |
| Levelized cost of energy [$/kWh] | 0.101 | 0.071 | 0.111 | 0.089 | 0.082 | 0.065 | 0.088 |

*Table 24 : Net present cost and Levelized cost of energy for the Western Zone of the ECOWAS*

The results are obtained with the respective interest rate of each country and a discount rate equal to the interest rate. Total costs total $138,067 million, and the levelized cost of energy varies between $0.055/kWh and $0.118/kWh.

For the single market strategy, a discount rate of 7% and a load factor of 0.70 are applied for the whole sub-region, the achievement of these single markets is based on the same principles as the self-sufficient strategy. In this case, Ivory Coast, Ghana, Guinea, Nigeria, Senegal and Sierra Leone (with it hydropower potential) are considered exporters. The other Member States are importing countries. A general review in the form of a table is carried out, allowing the different strategies to be compared.

In a first variant, the unified market is based on existing power plants, regional impact projects and projects with a national impact with a fixed commissioning date. The following assumption has been applied: the annuities of existing power plants concern only the owner countries and therefore have no impact on the market. Candidate thermal power plants: CC4, CCGN & OCGT9, will be allocated to natural gas exporting and producing countries only. The hydraulic power plants decided and envisaged will all be installed initially in order to promote the objectives of ECOWAS. Nevertheless, in a market situation, investors look for quick amortizations, so projects with large investments are often excluded during planning. A study will be carried out on this variant n°1 by removing all hydraulic projects that have a high investment cost (Variant n°1 bis).

In a second and third variant, a share of local production will be fixed, identically for all importing countries, and ensured by national impact projects. Also, candidate plants will be added if necessary. The remaining generation share will be distributed with regional impact projects and candidate thermal power plants in exporting countries.

[22] (Prioretti, 2018)

| Variant n°1(bis) : WAPP Strategy |
| --- |
| - Demand : Sum of all countries electricity needs<br>- Existing fleet : All existing power plants<br>- Projects : Thermal and Hydropower plants with a regional and national impact<br>- Candidates power plants : CC4, NGCC & OCGT9 distributed in export countries |

*Table 25 : Variant n°1 criteria*

| Variant n°2 & 3 : 40-60% of local production | |
| --- | --- |
| **Local share (Each country studied individually):**<br>- Demand : 40-60% of the needs for the import countries<br>- Existing fleet : Existing power plants of each country<br>- Projects : Thermal and Hydropower plants with a national impact<br>- Candidates power plants : Power plants selected according to the country studied<br>- Discount rate and interest rate according to the studied country | **Regional share**<br>- Demand : Sum of electricity needs of export countries+ remaining demand of import countries<br>- Existing fleet : existing power plants of export countries<br>- Projects : Thermal and hydropower plants with a national and regional impact<br>- Candidate power plants : CC4, NGCC & OCGT9 distributed in export countries<br>- Discount rate and interest rate of the sub-region |

*Table 26 : Variant n°2 and n°3 criteria*

A fourth variant will be studied with a renewable share of production included in the WAPP strategy.

## 5.1. WAPP strategy : Variant n°1

For the single market, the energy demand and demand power of all countries have been summed to represent the sub-region as a whole. All existing plants and their decommissioning years have been taken into account and represent the existing system in 2018. The projects, have been taken into account in the planning and set with a commissioning date.

In the energy planning of the generating fleet, these projects are commissioned on the agreed date. To fully meet the demand, candidate thermal projects are added. They are represented by CC4, NGCC and OCGT9 which are respectively combined cycles and gas turbines, using natural gas as fuel. Their respective distribution is made in the countries supposed to be exporters and producers of natural gas. Their number is first calculated to meet the national demand of these countries and then additional power plants are added to meet the total demand of the sub-region.
During a first simulation, with the results obtained, it can be seen that not all petroleum fuel thermal power plants were used. This results in fixed costs and annuities that the sub-region must pay for these plants. A second simulation was launched by removing these unused plants on the assumption that, the countries where these unused plants are located, are responsible for the remaining liabilities.
The levelized cost of energy thus decreases from $0.061/kWh to $0.057/kWh and the total net present cost decreases from $133,899M to $133,146M.

A balance of energies and powers for each type of resource is shown in Table 34 and Table 35.

The distribution of candidate thermal power plants in Ivory Coast, Ghana, Nigeria and Senegal was made proportionally to the demand of each country.

The share of local production varies greatly within importing countries, depending on their potential and the costs that may be incurred. The weighted production cost of this variant is $0.055/kWh. This cost is more attractive for most countries in the region than the costs of the self-sufficient strategy.

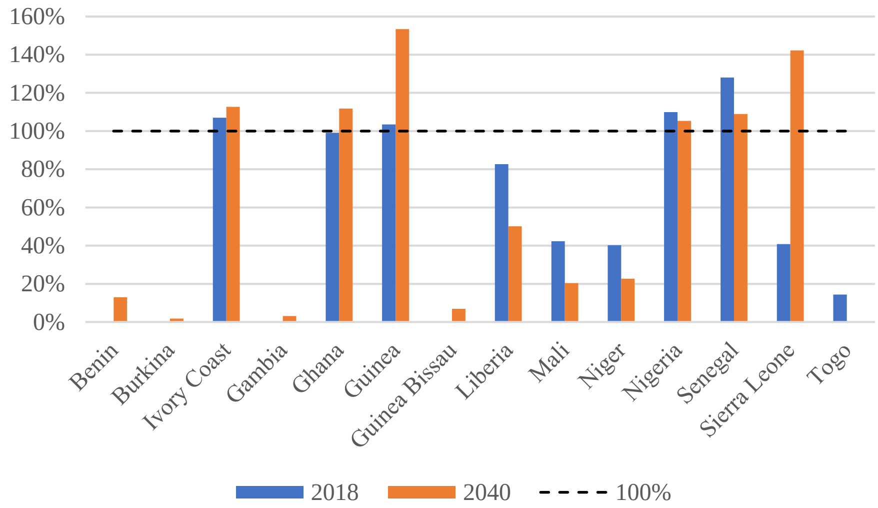


*Figure 15 : Evolution of the local share production*

With the two summary tables and the figure above two elements are striking:

- The share of local production in import countries varies significantly in both 2018 and 2040. It may decrease or increase as years and projects are planned per country. This is why a study is carried out on the influence of the share of local production in import countries with variants 2 & 3.

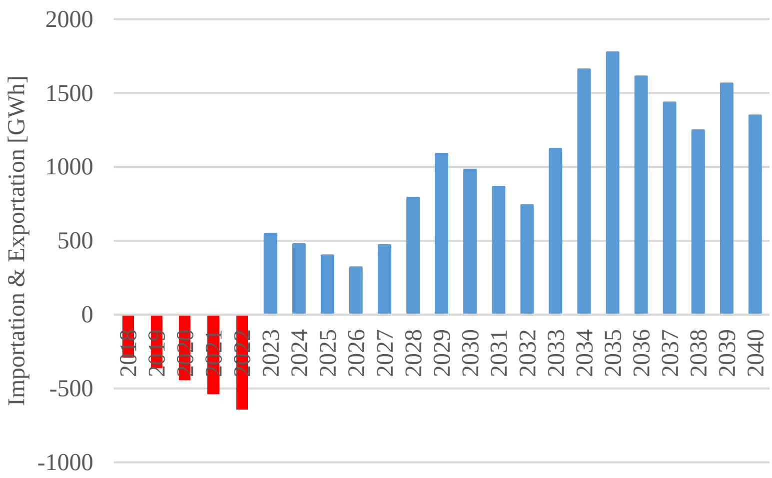


*Figure 16 : Exportation capacity of the Sierra Leone*

- The fact that Sierra Leone becomes an export country between 2018 and 2040 and exports up to 1348 GWh in 2040. This change in status is mainly due to the hydraulic projects carried out from 2023 onwards. Energy from hydropower in 2040 is 20 times higher than in 2018 and exceeds the country's energy demand.

In the appendices are available the energies produced for each country between 2018 and 2040 as well as the powers installed (Table 36, Figure 38 & Figure 65). In the following sub-section, Sierra Leone will be considered as an export country.

### 5.1.1. Comparison of the WAPP strategy with the self-sufficiency strategy

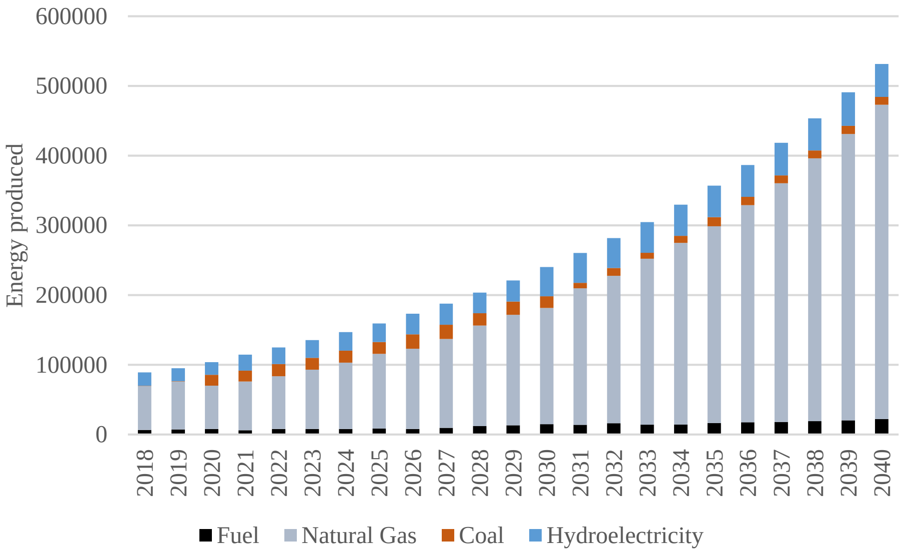


*Figure 17 : Energy produced by fuel type for the self-sufficient strategy*

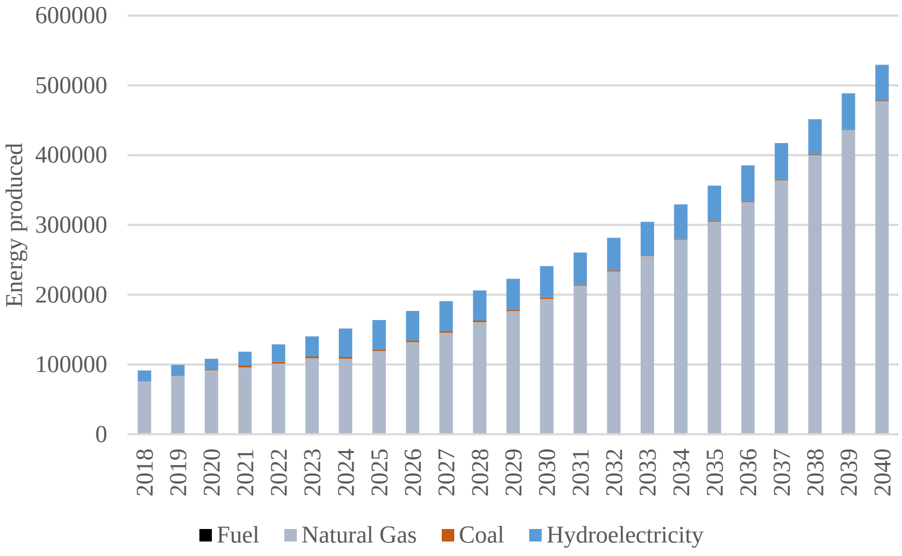


*Figure 18 : Energy produced by fuel type for the single regional market strategy (WAPP strategy)*

For both strategies, hydropower generation evolves in the same way. In 2018, production from hydroelectricity represents about 20% and only 10% in 2040. Production from petroleum fuels increases for the self-sufficiency strategy between 2018 and 2040. For variant 1 of the WAPP strategy, petroleum products are not used to produce electricity. Finally, the share of production from coal is higher for the self-sufficiency strategy than for the WAPP strategy. This is due, in the same way as oil production, to the fact that this type of power plant is intended for production on a national scale and therefore little used in the context of market unification.

The levelized cost of energy of the WAPP strategy is equal to $0.055/kWh. This cost is economically advantageous for all countries. Ivory Coast's production cost under the self-sufficiency strategy is equal to the production cost of the WAPP strategy, which is why this strategy is being reviewed on the assumption that the planned hydropower plants (with no commissioning date) with significant investment and low hydraulic potential will never be built.

#### 5.1.2. WAPP strategy : deleting of hydraulic projects without implementation date with high investment costs.

For variant 1 of the WAPP strategy, all hydropower plants with fixed or undefined commissioning dates are commissioned between 2018 and 2040 without taking into account their investment or energy production potential. This is for purely energy purposes. In addressing the economic problem, some hydropower plants represent significant costs, which has consequences on the total net present cost and the weighted cost of production. Moreover, when it comes to the market, investors are more likely to invest in projects where amortizations are made quickly, which is why projects with a long amortization period are often excluded. In this variant, hydraulic power plants with no commissioning date and high investment costs have been eliminated.
The result obtained is the expected result of a reduced capital cost and a reduced weighted cost of production from $0.055/kWh to $0.053/kWh and a saving on net present cost of $700 million.

#### 5.1.3. Sensitivity analysis of the WAPP strategy

A sensitivity analysis is carried out on the regional market strategy. This is done by varying the discount rate of the study between 6 and 10%, here are the results:

| **Regional market** | | | **Regional market without hydraulic projects** | | |
|---|---|---|---|---|---|
| Taux d'actualisation | Total cost | LCOE | Taux d'actualisation | Total cost | LCOE |
| 6% | 144’911 | 0.053 | 6% | 143’989 | 0.0525 |
| 7% | 130’976 | 0.0535 | 7% | 130’201 | 0.053 |
| 8% | 118’941 | 0.054 | 8% | 118’280 | 0.0535 |
| 9% | 108’515 | 0.0545 | 9% | 107’938 | 0.054 |
| 10% | 99’418 | 0.055 | 10% | 98’932 | 0.545 |

*Table 27 : Sensitivity analysis*

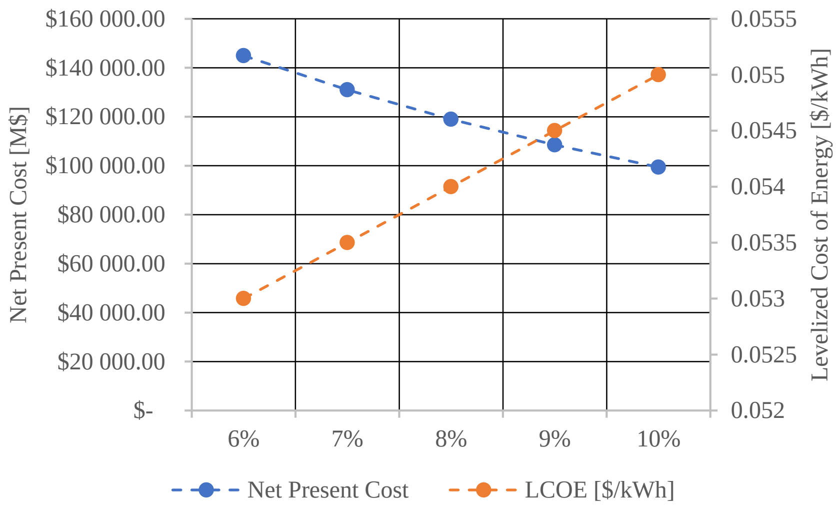


*Figure 19 : Discount rate influence*

With the Table 27 and Figure 19, it can be seen that the higher the discount rate, the lower the NPC. This result was expected since under the NPC formula, increasing the discount rate increases the value of the denominator, which means that the invested money loses value faster than with a lower discount rate. It can be seen that when the discount rate increases the weighted cost of production also increases, so the money invested during the project will yield more (taking into account risk aversion), thus a higher weighted cost of production. Moreover, the energy produced is not directly proportional to the net present costs.

## 5.2. <u>40%-60% of local production : Variant n°2 & n°3</u>

As shown in Table 26, importing countries have a share of production to be provided through local projects. In this variant the share of local production is 40% and 60%. The local fleet must provide 40% and 60% of the demand with a good quality of service. The remaining part of the demand of these importing countries, plus the demand of exporting countries, is met by a regional production fleet comprising the countries of the subregion (Figure 66 - Figure 87). The production parks are detailed in the appendix (Table 37 - Table 40)

### 5.2.1. <u>Comparison of the levelized cost of energy</u>

| Variant | Benin | Burkina Faso | Gambia | Guinea-Bissau | Liberia | Mali | Niger | Togo | ECOWAS Remain share | All the region |
|---|---|---|---|---|---|---|---|---|---|---|
| WAPP | - | - | - | - | - | - | - | | 0.055 | 0.055 |
| 40% local share | 0.077 | 0.097 | 0.084 | 0.085 | 0.085 | 0.089 | 0.068 | 0.067 | 0.055 | 0.057 |
| 60% local share | 0.081 | 0.114 | 0.095 | 0.097 | 0.097 | 0.105 | 0.071 | 0.072 | 0.055 | 0.058 |
| Self-sufficiency | 0.092 | 0.118 | 0.101 | 0.111 | 0.089 | 0.082 | 0.074 | 0.080 | - | - |

*Table 28 : Levelized cost of energy depending on the chosen strategy*

With this table, it can be seen that the higher the local share production for the import countries, the higher is the levelized cost of energy for these countries.

For the 40% and 60% local production variants, the weighted production costs decrease with the increase in local share, but the repercussions are felt throughout the region. With 40% local production, the weighted cost of production is lower than with 60% local production.

From an overall economic point of view, it is more interesting to rely on the major energy powers of the sub-region: the weighted cost of production is more interesting for the majority of countries.

To establish the weighted cost of production for the entire region, for the different variants, the ratio of the annual net present cost to current energy production for all countries must be summed. The calculation is as follows:

$$LCOE = \sum_{i=Benin}^{Togo} \left( \sum_{t=2018}^{2040} \frac{NPV_{t,i}}{Ep_{t,i} / (1+a_i)^{t-2018}} \right);$$

- $LCOE$ : Levelized cost of energy for all the region [$/kWh]

As for the variant n°1, Hydraulic power plants with a high investment costs have been deleted of the planning for the variant n°2 and n°3.

### 5.2.2. Comparison of the energy produced by fuel type

A comparative analysis of the amount of energy produced for each strategy is carried out in order to present the significant changes between the self-sufficiency strategy and the single regional market strategy.

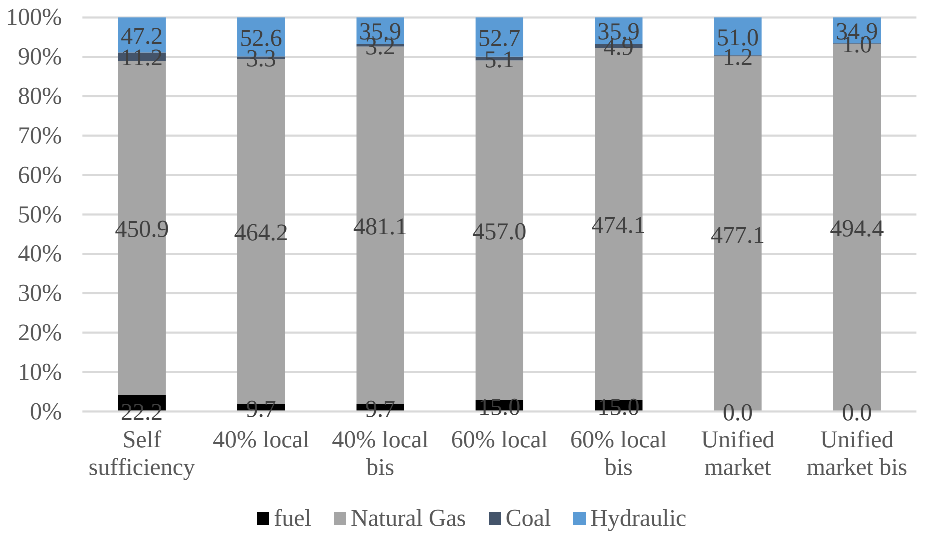


*Figure 20 : Electricity production by fuel type for each strategy. Results for 2040*

Seven variants of production plants were built over the period of study. The strategies in question correspond to the strategies from which the hydraulic projects envisaged with a high investment cost and a low potential for energy production leading to a high levelized cost of energy have been eliminated.

In 2040, it can be seen that the share of oil decreases as we move closer to market unification. Most of the power plants using petroleum fuels are used for local production and are small in size. Thus, the more the market tends to unify, the more the use of this type of power plant will decrease until it disappears from the single market strategy. This dynamic also applies to coal-fired power plants, since their impact can only be measured at national level, as they move towards market unification and multinational interconnection, coal use will tend to decrease. However, it is not zero because Niger remains a producer, using coal as a source of electricity production, however small it may be.

Without considering the alternative bis, hydraulic production is more important once the self-sufficiency strategy is not chosen. With a share of local production imposed on import countries, hydropower production is slightly larger than for the WAPP strategy; this is explained by the fact that importing countries must provide 40%-60% of their demand and that it is more optimal for them independently of the sub-region to involve small hydropower plants. These small power plants have not been built under the WAPP strategy because the countries considered as importers, do not have the obligation to ensure a share of production themselves.

Comparing the variants with the alternative bis variants shows that the energy produced from hydropower decreases at the expense of the energy produced from gas-fired power plants, with a lower levelized cost of energy and a lower net present cost.

### 5.3. The renewable production : Variant n°4

This variant follows the first variant, there are no constraints on the local share production for the import countries. This variant introduces renewable energies and follows a regional scenario from the IRENA.

In the first step, a review of the technologies, their economic and technical data will be compiled. In a second step, the strategy adopted and the methodology used will be presented.[23][24]

- Photovoltaic solar panels : Photovoltaic (PV) converts sunlight directly into electricity. Today, photovoltaics is one of the fastest growing renewable energy technologies and is ready to play a major role in the future global mix of electricity production.
  Solar photovoltaic installations can be combined to provide electricity on a commercial scale, or organized into smaller configurations for mini grids or personal use.
  The cost of manufacturing solar panels has dropped dramatically over the past decade, making them not only the most affordable but often the cheapest form of electricity. Solar panels have a lifetime of about 25 years.
  The countries with the most potential are the countries furthest from the coast such as Burkina Faso, Mali, Niger and Nigeria.

[23] (IRENA, International Renewable Energy Agency, 2018)
[24] (IRENA, Planning and prospects for renewable power : West Africa, 2018)

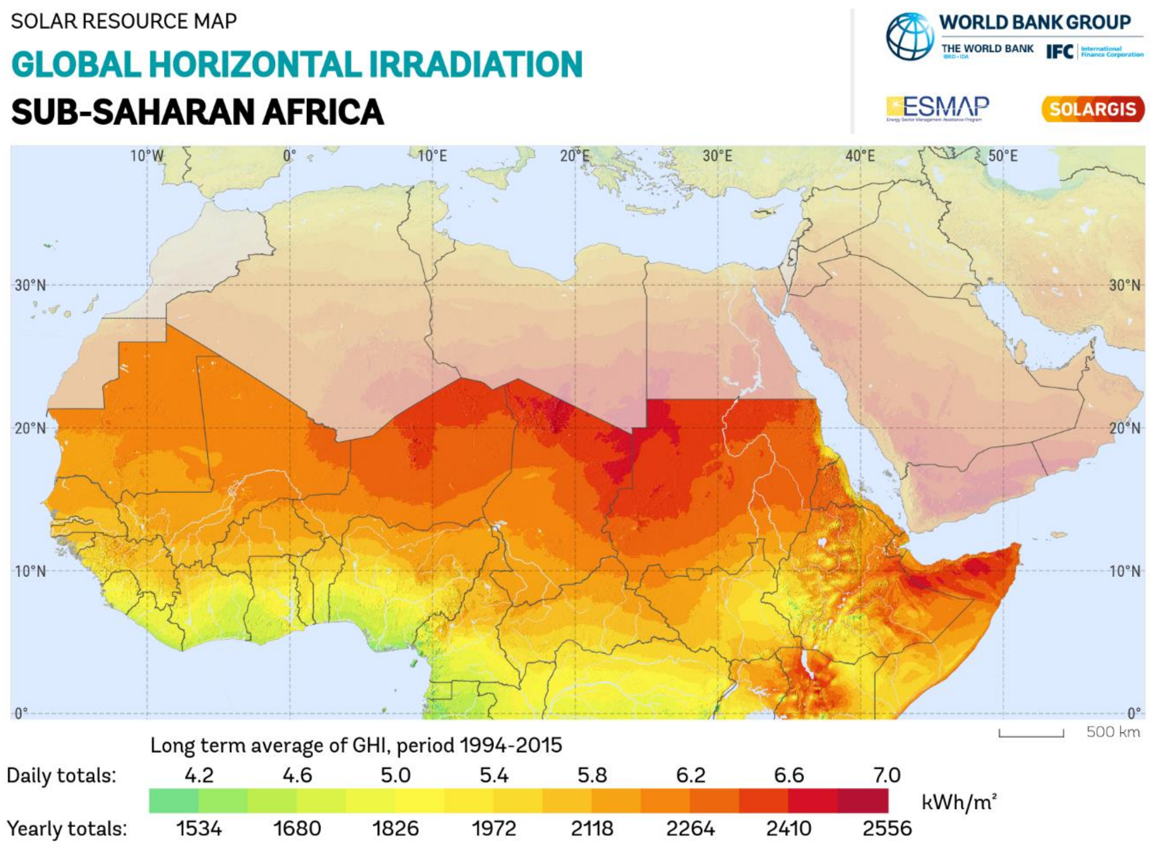


*Figure 21 : Global Horizontal Irradiation in Sub-Saharan Africa*[25]

- <u>Concentrated solar energy</u> : Concentrated solar energy (CSP), uses mirrors to concentrate solar rays. These rays heat the fluid, which creates steam to drive a turbine and produce electricity. CSP is used to produce electricity in large power plants.

  A CSP power plant is usually equipped with a field of mirrors that redirect the rays to a tall, thin tower. One of the main advantages of a CSP plant compared to a solar photovoltaic plant is that it can be equipped with molten salts in which heat can be stored, which makes it possible to produce electricity once the sun sets.

  The countries with the most potential for concentrated solar energy are Mali and Niger.

[25] (Global Solar Atlas , s.d.)

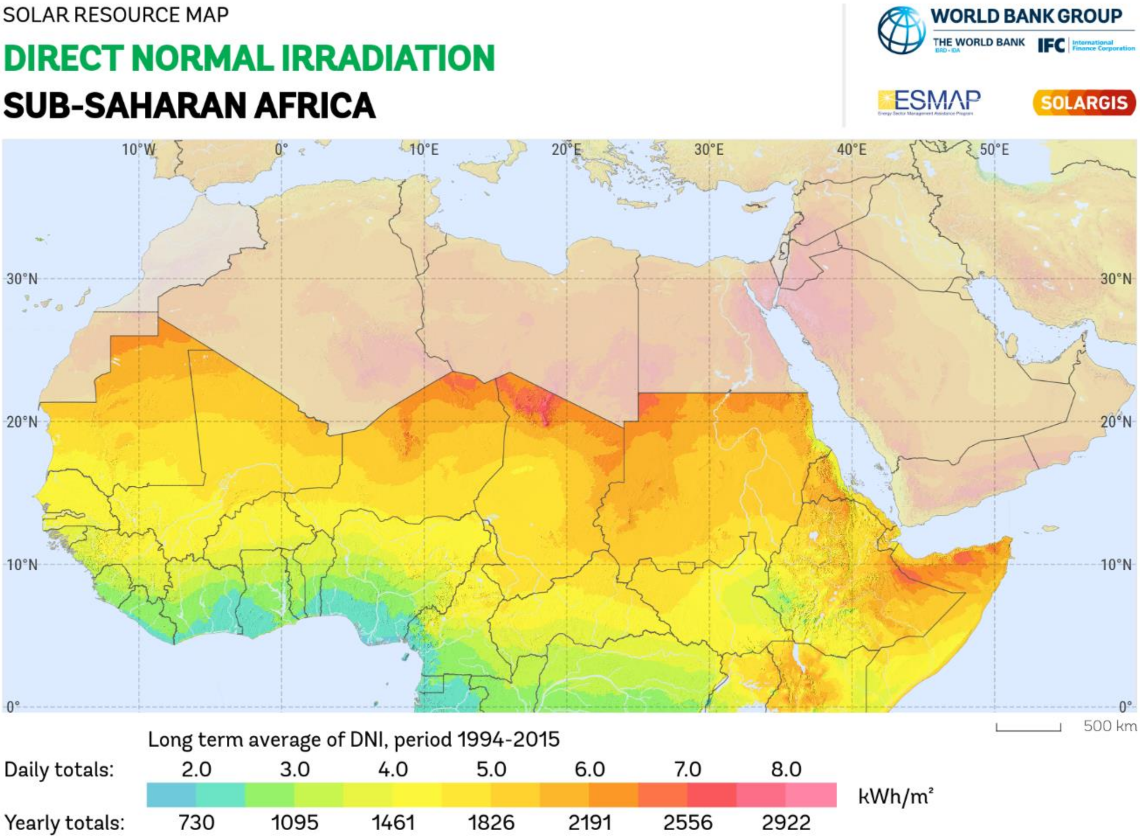


*Figure 22 : Direct normal irradiation in sub-saharan Africa*[26]

- Wind turbines : Wind turbines were created more than a century ago. After the invention of the electric generator in the 1830s, engineers began to try to harness wind energy to produce electricity.

  Wind is used to produce electricity by using the kinetic energy created by moving air. This is transformed into electrical energy using wind turbines or wind energy conversion systems. The wind first hits the blades of a wind turbine, causing them to turn and the turbine connected to them to turn. This changes the kinetic energy into rotational energy, by moving an axis connected to a generator and thus producing electrical energy by electromagnetism.

  The amount of energy that can be produced by the wind depends on the size of the wind turbine and the length of its blades. The efficiency is proportional to the dimensions of the rotor and the cube of the wind speed: Betz formula.

  Two countries in the region have much higher potential than the other countries, Niger and Nigeria.

[26] (Global Solar Atlas , s.d.)

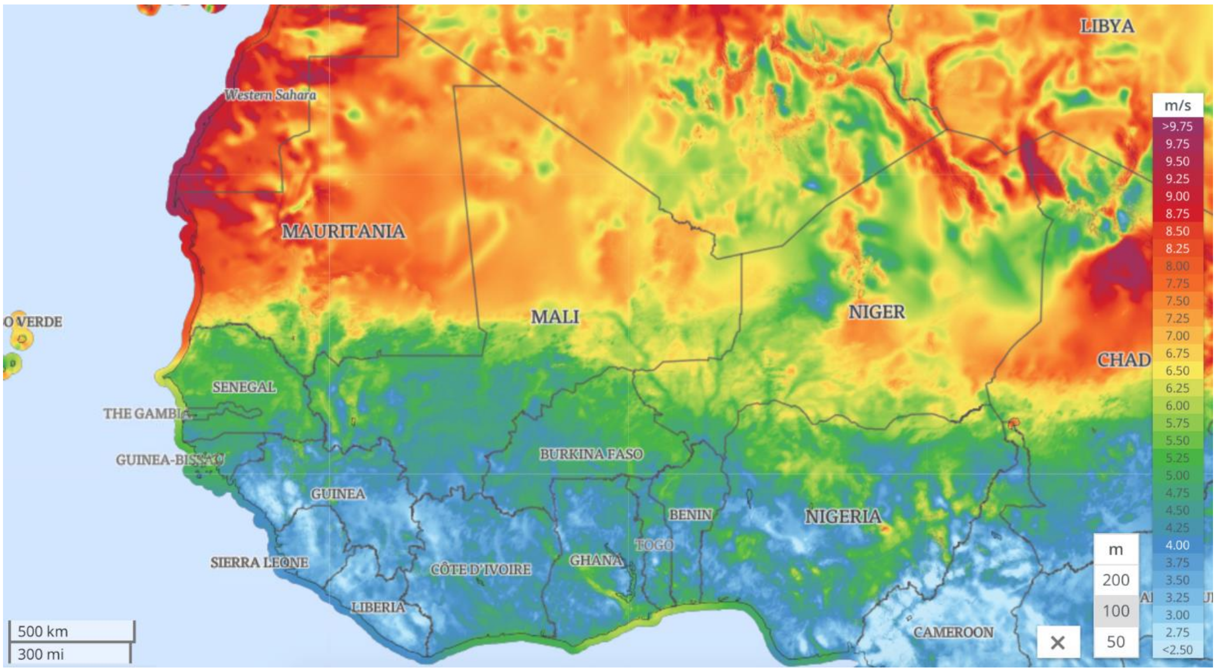


*Figure 23 : Average wind speed in sub-saharian Africa*[27]

- <u>Biomass</u> : Biomass is used to produce electricity by burning materials (wood, plants, agricultural waste, organic household waste) or biogas from the fermentation of these materials in biomass power plants. There are two main types of biomass:
  - Biomass by combustion: waste is directly burned by producing heat, electricity or both (cogeneration). This concerns wood, waste from wood processing industries and agricultural plant waste (straw, sugar cane, groundnuts, coconuts, etc.).
  - Biomass by methanation: waste is first transformed into biogas by fermentation using microorganisms (bacteria). The biogas is then burned. This biogas is close to natural gas and mainly composed of methane. This concerns household waste, animal manure and slurry, sewage sludge, paper and cardboard...

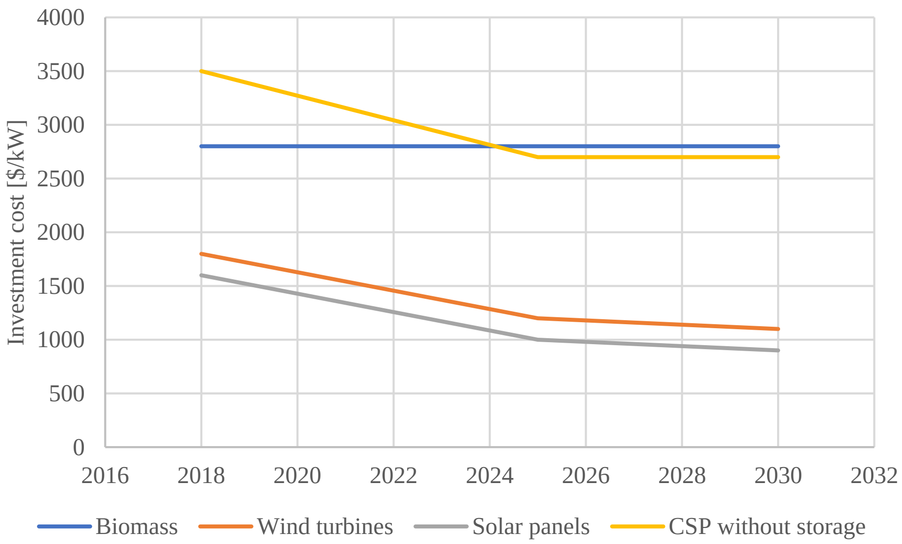


*Figure 24: Evolution of the investment cost of renewable energies*

[27] (Global Wind Atlas, s.d.)

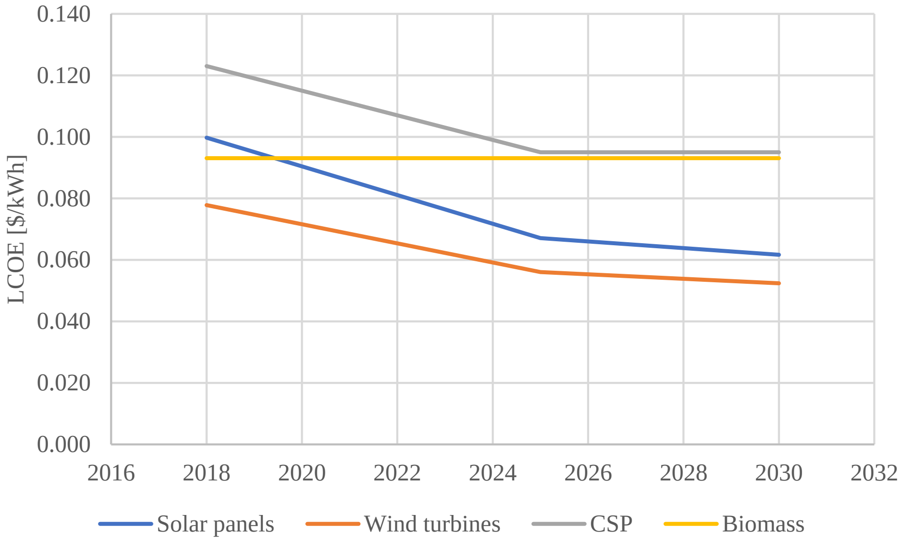


*Figure 25 : Evolution of the LCOE of renewable energies*

| | Fixed O&M [$/MW] | Variable O&M [$/MWh] | FC | Fuel cost [$/GJ] |
|---|---|---|---|---|
| Solar panels | 20000 | - | 0.18 | - |
| Wind turbine | 13000 | 7 | 0.27 | - |
| CSP | - | 35 | 0.6 | - |
| Biomass | 120000 | 20 | 0.5 | 1.6 |

*Table 29 : Economic and technical datas for renewable energies*

With the Table 29 & Figure 24, Figure 25adapted to the IRENA regional scenario, the evolution of the renewable fleet will follow the same dynamic of evolution as the global production fleet between 2030 and 2040. The installed capacity targets for the various renewable energies are as follows:

| Year | Solar PV | Wind turbines | CSP | Biomass |
|---|---|---|---|---|
| 2018 | 172 | 0 | 0 | 0 |
| 2020 | 1000 | 800 | 0 | 1100 |
| 2030 | 8500 | 1600 | 0 | 4500 |
| 2040 | 16984 | 3197 | 0 | 8992 |

*Table 30 : Installed power evolution*

More precisely, each year, here is the evolution of the installed powers for each technology:

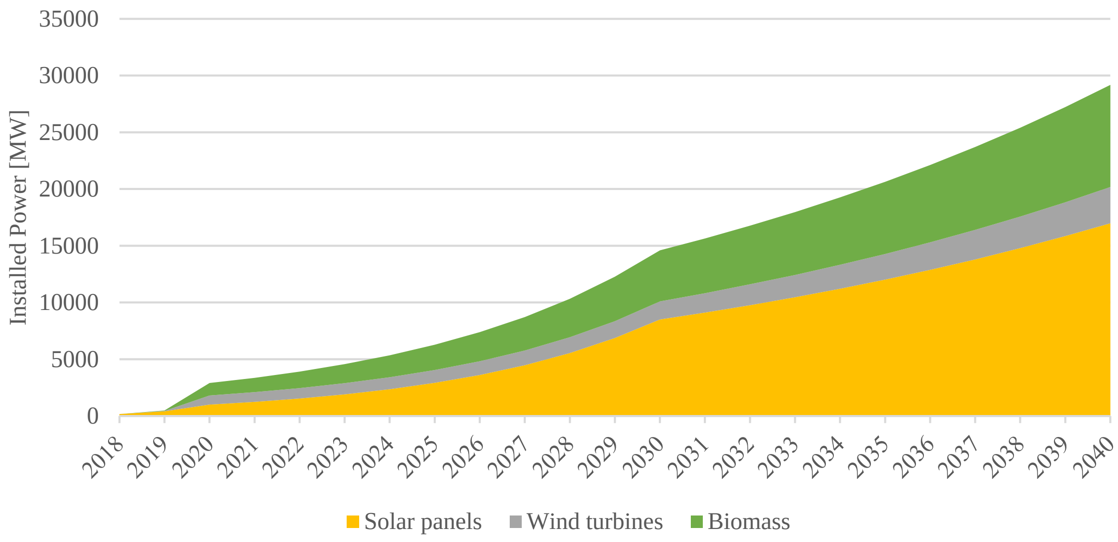


*Figure 26 : Installed power evolution from 2018 to 2040*

The energy produced by each technology is obtained by multiplying the installed power by the load factor and the number of hours in the year.
For each year thereafter it is possible to calculate the Net present cost:

$$NPV_{i,t} = \frac{(P_{i,t} - P_{i,t-1}) * I_{i,t} + P_{i,t} * O\&M_{f,i} + E_{i,t} * O\&M_{v,i} + Cons_i * E_{i,t}/r_i - VR_{i,t}}{(1+a)^{t-2018}}$$

With :

- $P_{i,t}$ : Installed capacity in the year *t* of renewable technology *i*
- $I_{i,t}$ : Investment cost in the year *t* of renewable technology *i*
- $O\&M_{f,i}$ : Fixed operation and maintenance costs for the renewable technology *i*
- $O\&M_{v,i}$ : Variable operation and maintenance costs for the renewable technology *i*
- $E_{i,t}$ : Energy produced by the renewable technology *I*, in the year *t*
- $Cons_i$ : Fuel cost for the renewable technology *i*
- $r_i$ : Efficiency of the technology *i*
- $VR_{i,t}$ : Residual value of the technology *i*, in the year *t*

The formalized method for the residual value is based on a repayment with a constant annuity over the lifetime and calculates the residual value from the non-payed portion.

To have the total NPC of a technology over the entire duration of the study, simply add the NPC of each year of this technology.

To obtain the levelized cost of energy for each renewable technology, the ratio of total NPC to total updated energy is calculated as follows for each technology and the results are as follows (in relation to Figure 25):
Photovoltaic solar panels: $0.062/kWh
Wind turbines: 0.059$/kWh
Biomass: $0.092/kWh

Biomass remains particularly expensive to produce, but it should be recalled that this study was carried out on the basis of stable fuel prices (biomass, oil, gas), whereas the latter tend to fluctuate over time.

To calculate the weighted cost of production of this strategy:

- The net present costs and energy produced for each year of variant 1 are required.

- The production of energy from renewable sources is subtracted from energy from gas-fired power plants. The size of the thermal fleet does not change, only it produces less. We therefore replace production from gas-fired power plants with production from renewable sources.

- If gas production decreases then fuel costs decrease as well: to calculate this cost saving, multiply the amount of energy from renewable sources by the price of gas and divide by the efficiency of gas-fired power plants.

- To calculate the net present cost of this variant, the net present costs of renewable energies are added to the net present cost of variant 1. This is subtracted from the discounted fuel economy and thus the discounted variable operating and maintenance costs savings.

- To obtain the levelized cost of energy of this strategy, the net present cost plus the interests of the existing system must be divided by the total discounted energy of the fleet.

$$NPV_{ER,tot} = NPV_{var°1} + \sum NPV_{i,t} - E(C)_{act} - E(O\&M)_{act}$$

$$LCOE_{ER,tot} = {(NPV_{ER,tot} + Int_{2018})}\Big/_{Etot_{act}}$$

With:

- $NPV_{ER,tot}$ : Net present cost of the WAPP strategy with renewable energy
- $NPV_{var°1}$ : Net present cost of the first variant
- $\sum NPV_{i,t}$ : Sum of Net present costs of renewable energies
- $E(C)_{act}$ : Net present economy of gas fuel
- $E(O\&M)_{act}$ : Net present economy on the O&M costs of gas power plants
- $LCOE_{ER,tot}$ : Levelized cost of energy of the WAPP strategy with renewable energy
- $Int_{2018}$ : Interest of the 2018 fixed system
- $Etot_{act}$ : Net present produced energy by the power plant.

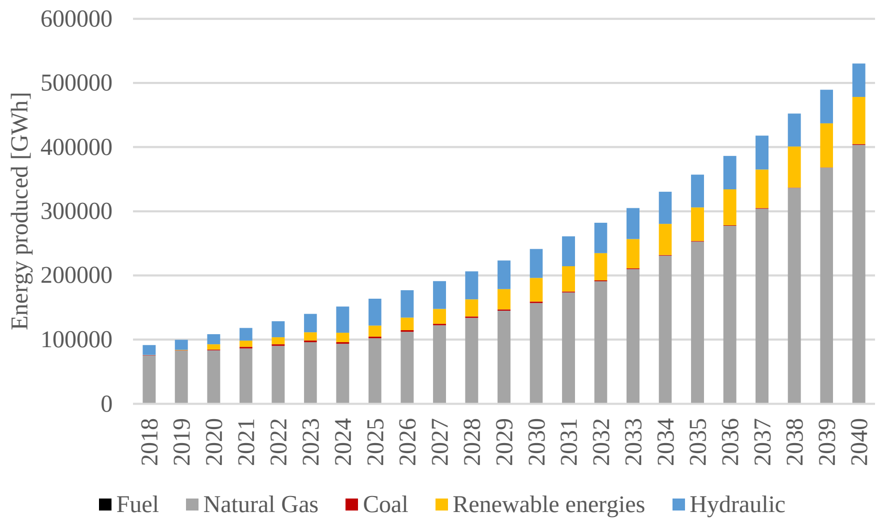


*Figure 27 : Energy produced by fuel type in a single regional market – WAPP*

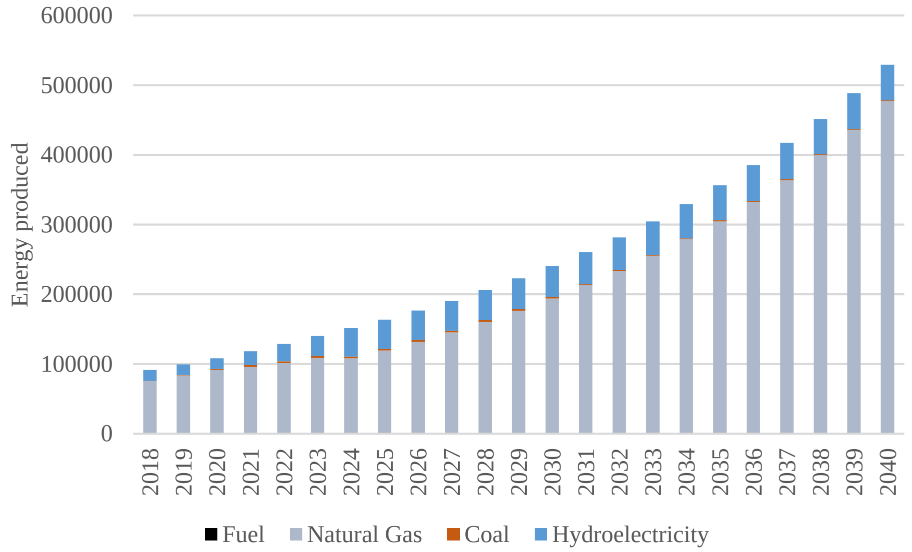


*Figure 28 : Energy produced by fuel type for the WAPP strategy without renewable energy*

By comparing the unified market strategy of variant 1 with that of variant 4, it can be seen that gas production is decreasing at the expense of energy production from renewable projects (solar wind & biomass). The choice to leave the same thermal fleet in both variants is justified by the fact that renewable energies are intermittent energies and that it is necessary to ensure electricity production and quality of service at all times. Thus, in the event of bad weather and non-renewable production, the thermal fleet is able to fill this production gap. This results in higher investments and a higher weighted cost of production. If the fleet sized to meet the IRENA scenario were chosen, the weighted cost of production would increase from $0.055/kWh to $0.059/kWh.

## 5.4. Economic comparison for all strategies

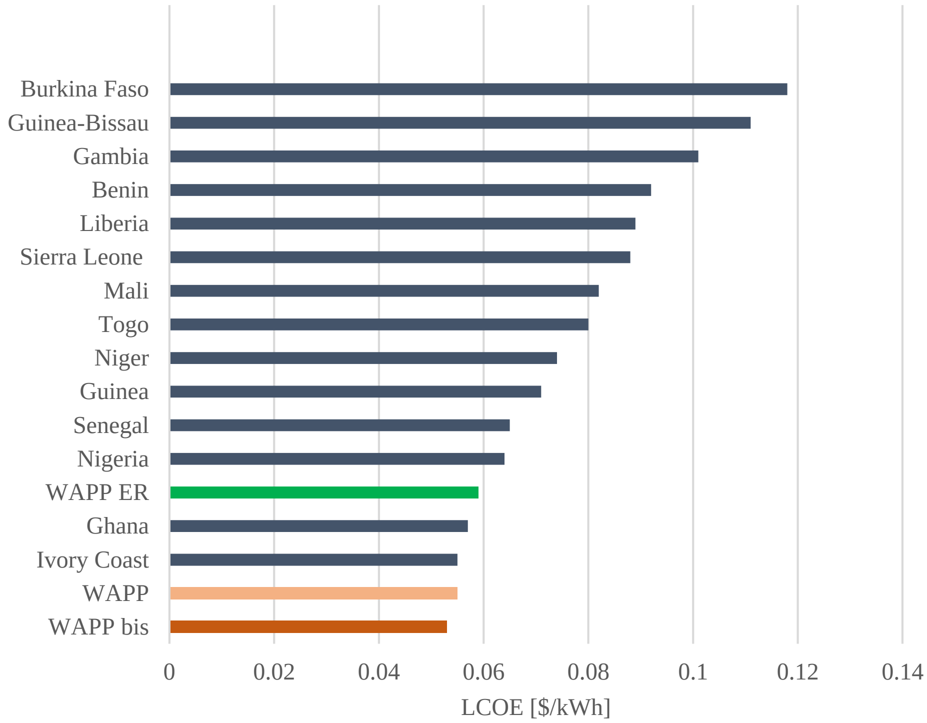


*Figure 29 : Different levelized costs of energy*

With the Figure 29, overall, the WAPP strategy is more economically interesting than the self-sufficiency strategy. And even more interesting if gas-fired thermal power plants are built instead of some economically unviable hydraulic projects.

Introducing more renewable energies would lead to additional costs and a higher levelized cost of energy but would introduce added value on the environmental aspect.

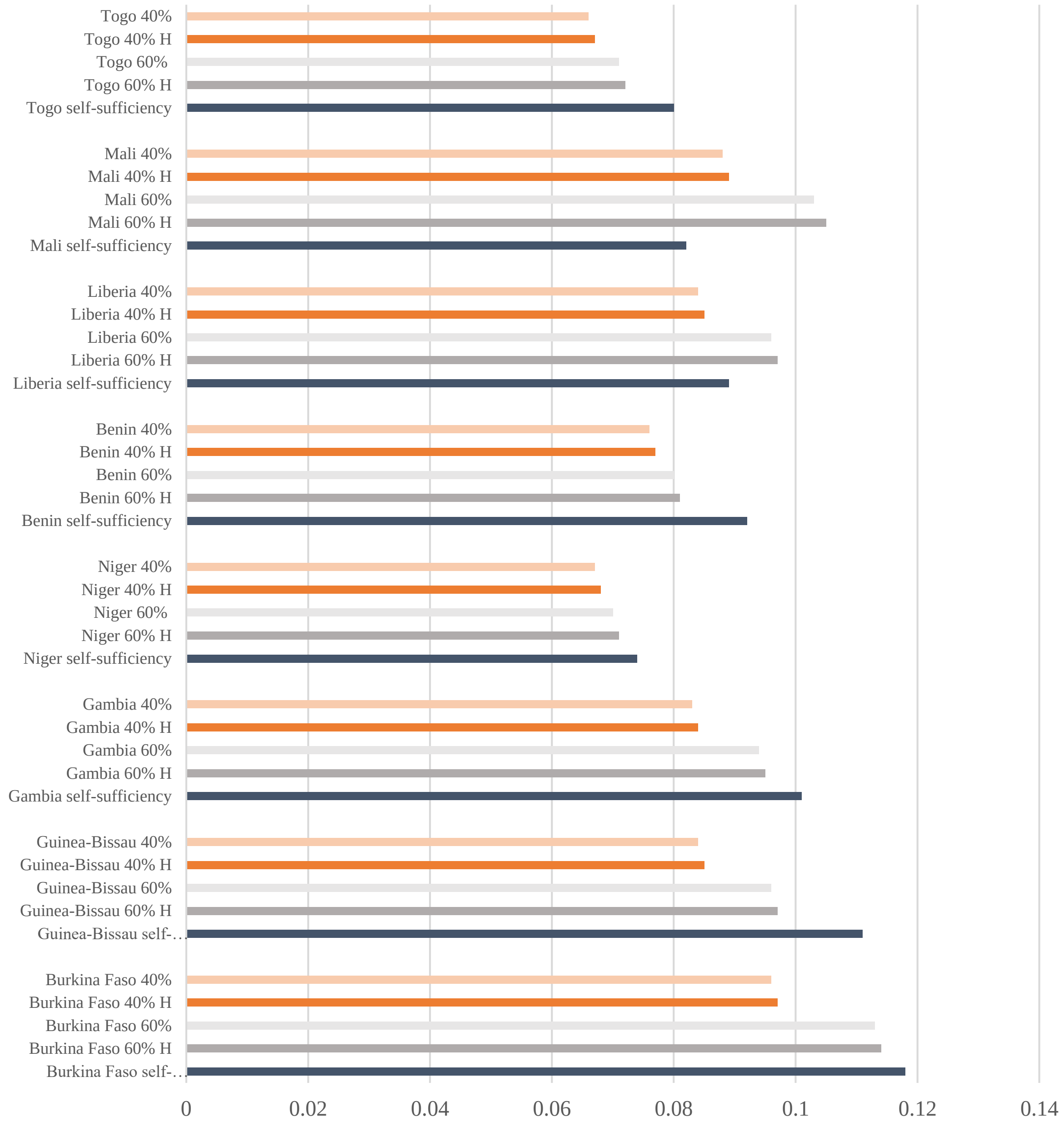


*Figure 30 : Levelized costs of energy for import countries in different strategies (H : with hydraulic projects included)*

The results show that the more the share of local production decreases, the more interesting the weighted cost of production becomes. It is important to note that for countries such as Mali and Liberia, the autarkic strategy may be more interesting than a strategy with a share of local production, this is due to the fact that OMVS (Mali) projects were considered in the market and not in local production.

## 6. Limit of the Study

During this sequence, some limits were observed, these are of different kinds but it is important to be able to present them. Assumptions necessarily tend towards finite limits:

Considering a constant price for fuels and the evolution of costs for the different technologies is a limit. From experience, it is easily observable that fuel prices are volatile and difficult to determine for the future. Similarly, for the different technologies, there is a variability of costs over time, some costs increase and others decrease.

Only one hydrological condition has been taken into account for all countries, whereas there are mainly two seasons in this region of the world: the dry season and the rainy season of different duration and intensity depending on the geographical situation of the countries.

Discount and interest rates are also a limit, they are based on a study and ratings assigned according to criteria, the values chosen remain subjective.

## Conclusion

The energy situation of the ECOWAS member countries is in full transition with the pooling of the region's resources in order to meet the needs of the entire population with a good quality of service. The main question of this study is whether this pooling of resources is more interesting than simply strengthening production at the local level (self-sufficiency strategy).

To meet these needs, the two strategies were modelled by taking into account the existing fleet, the different costs, the expansions of the fleet, the projects decided upon and the projects envisaged: represented by candidate power plants.

The strategies were compared from a national and global point of view by analysing different shares of local production for the countries considered importers.

With the assumptions made and the results obtained, it can be said that the objective of pooling resources and unifying the market is more economically favourable for the majority of countries. With variants imposing a share of local production on importing countries, this leads to an increase in the net present costs and weighted production costs for the entire sub-region. In any case, it is easy to observe that it is not interesting for importing countries to turn to a self-sufficiency policy, despite the fact that politically no one wants to be dependent on other countries. For all countries, the quality of service is better thanks in particular to a larger shared reserve margin.

The interest of this unification strategy is not only global, it is also national, and countries must be ready to engage in this unified regional market policy.

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# Appendices

| Name | Group | Capacity [MW] | Implementation |
|---|---|---|---|
| AZURA | Gas turbine | 450 | Planned |
| AFAM III | Gas turbine | 240 | Planned |
| OKPAI IPP II - AGIP | Gas turbine | 300 | Planned |
| OKPAI IPP II - AGIP | Gas turbine | 150 | Planned |
| IBOM II | Gas turbine | 552 | Planned |
| ASCO | Gas turbine | 110 | Planned |
| ELEME | Gas turbine | 75 | Planned |
| QUA IBOE POWER PLANT | Gas turbine | 520 | Planned |
| Cummins Power Gen Ltd | Gas turbine | 150 | Planned |
| ONDO IPP - King Line | Gas turbine | 200 | Planned |
| Turbine Drive | Gas turbine | 501 | Planned |
| EGBIN 2+ | Gas turbine | 1200 | Planned |
| EGBIN 2+ | Gas turbine | 700 | Planned |
| SAPELE POWER PLC | Gas turbine | 600 | Planned |
| ZUMA | Coal power plant | 374 | Planned |
| PARAS | Gas turbine | 300 | Planned |
| OMA POWER GEN COMP | Gas turbine | 500 | Planned |
| CENTURY IPP | Gas turbine | 496 | Planned |
| BRESSON NIGERIA Ltd | Gas turbine | 90 | Planned |
| SAPELE POWER PLC | Gas turbine | 100 | Planned |
| ETHIOPE | Gas turbine | 344 | Planned |
| ONDO IPP - King Line | Gas turbine | 150 | Planned |
| ONDO IPP - King Line | Gas turbine | 200 | Planned |
| ETHIOPE | Gas turbine | 156 | Planned |
| PROTON | Gas turbine | 150 | Planned |
| ZUMA | Gas turbine | 1200 | Planned |
| DELTA III 2+ | Gas turbine | 143 | Planned |
| DELTA IV 2+ | Gas turbine | 594 | Planned |
| LAFARGE PHASE I | Gas turbine | 50 | Planned |
| CALEB INLAND | Gas turbine | 500 | Planned |
| ALSCON phase1 | Gas turbine | 100 | Planned |
| YELLOWSTONE | Gas turbine | 360 | Planned |
| ETHIOPE | Gas turbine | 344 | Planned |
| ETHIOPE | Gas turbine | 156 | Planned |
| IKOT ABASI | Gas turbine | 250 | Planned |
| LAFARGE PHASE II | Gas turbine | 220 | Planned |
| CALEB INLAND | Gas turbine | 500 | Planned |
| ALSCON phase 2 | Gas turbine | 260 | Planned |
| ESSAR | Gas turbine | 660 | Planned |
| GEREGU NIPP2 | Gas turbine | 285 | Planned |
| OMOTOSHO II 2+ | Gas turbine | 254 | Planned |
| CALEB INLAND | Gas turbine | 500 | Planned |
| SAPELE 2 -NIPP | Gas turbine | 453 | Planned |
| OATS | Gas turbine | 700 | Planned |

| | | | |
|---|---|---|---|
| GEREGU FGN1-2 | Gas turbine | 414 | Planned |
| CALABAR ODUKPANI - NIPP | Gas turbine | 254 | Planned |
| GBARAIN/UBIE 2 | Gas turbine | 115 | Planned |
| GEREGU NIPP 2 | Gas turbine | 444 | Planned |
| CALABAR ODUKPANI - NIPP | Gas turbine | 564 | Planned |
| EGBEMA II | Gas turbine | 127 | Planned |
| IHOVOR 2 - NIPP | Gas turbine | 254 | Planned |
| GBARAIN/UBIE 2 | Gas turbine | 904 | Planned |
| CHEVRON AGURA | Gas turbine | 780 | Planned |
| SUPERTEK | Gas turbine | 500 | Planned |
| MBH | Gas turbine | 300 | Planned |
| WESTCOM | Gas turbine | 500 | Planned |
| HUDSON POWER | Gas turbine | 150 | Planned |
| BRESSON AS NIGERIA | Gas turbine | 450 | Planned |
| AZIKEL IPP | Gas turbine | 76 | Planned |
| AZIKEL IPP | Gas turbine | 250 | Planned |
| AZIKEL IPP | Gas turbine | 163 | Planned |
| TOTALFINALELF | Gas turbine | 420 | Planned |
| ANAMBRA STATE IPP | Gas turbine | 528 | Planned |
| KNOX | Gas turbine | 501 | Planned |
| DELTA STATE IPP | Gas turbine | 500 | Planned |
| BENCO | Gas turbine | 700 | Planned |
| ASHAKA | Coal power plant | 64 | Planned |
| RAMOS | Coal power plant | 1000 | Planned |
| ASHAKA/TPGL | Coal power plant | 500 | Planned |
| KADUNA IPP | Gas turbine | 900 | Planned |
| NASAWARA COAL | Coal power plant | 500 | Planned |
| FORTUNE ELECTRIC | Gas turbine | 500 | Planned |
| FORTUNE ELECTRIC | Gas turbine | 500 | Planned |
| BENUE COAL POWER | Coal power plant | 1200 | Planned |
| ENUGU COAL POWER | Coal power plant | 2000 | Planned |
| GWAGWALADA | Combined cycle | 1350 | Planned |

*Table 31 : Thermal projects in Nigeria*

| Countries | Situation in 2018 – Decided projects – Planned projects | Situation in 2040 – Total cost (M$)<br>Levelized cost of energy ($/kWh) | Comments |
|---|---|---|---|
| Benin | Demand : 1309.3GWh<br>Load power : 261MW<br>Existing fleet : Hydropower plant = 32.5MW ; Thermal power plant = 163MW<br>Imports : Ghana 25MW ; Nigeria 100MW<br>Decided projects : Gas turbine 50MW (2020)<br>Planned projects : Thermal power plant 450MW ; Hydropower plant 245MW<br>**Available energy** : Thermal power plant = 450.3GWh ; Hydropower plant = 113.9GWh ; Imports = 876GWh<br>Candidates power plant : CC6 & OCGT8 | Demand : 5451.2GWh<br>Load power : 1086.8MW<br>Existing fleet : Hydropower plant = 0MW ; Thermal power plant = 65MW<br>Imports : Ghana 25MW ; Nigeria 300MW<br>Planned projects : Thermal power plant = 100MW ; Hydropower plant = 245MW<br>Candidates power plant : 5 CC6 & 1 OCGT8<br>**Available energy** :Thermal power plant = 3315.8GWh ; Hydropower plant = 402.9GWh ; Imports = 2278GWh<br>Total cost : **2629M$**<br>Levelized cost of energy : **0.092$/kWh** | Increase in imports from Nigeria. Increase in line capacity. All the planned hydraulic projects have been completed, but the resulting production is low with only 7.4% of the energy produced for 22% of the total installed capacity. |
| Togo | Demand : 1582.5GWh<br>Load power : 251.2MW<br>Existing fleet : Hydropower plant = 32.5MW ; Thermal power plant = 124.5MW<br>Imports : Ghana 25MW ; Nigeria 100MW<br>Decided projects : Gas turbine 40MW (2020) ; Hydropower plant 24.2MW (2023)<br>**Available energy** : Thermal power plant = 592.6GWh ; Hydropower plant = 113.9GWh ; Imports = 876GWh<br>Planned projects : Gas turbines ; Hydropower plant 250MW<br>Candidates power plant : CC6 & OCGT8 | Demand : 6324.7GWh<br>Load power : 1003.9MW<br>Existing fleet : Hydropower plant = 0MW ; Thermal power plant 99MW<br>Imports : Ghana 25MW ; Nigeria 300MW<br>Planned projects : Thermal power plant = 0MW ; Hydropower plant = 219.7MW<br>Candidates power plant : 5 CC6 & 1 OCGT8<br>**Available energy** : Thermal power plant = 3381.8GWh ; Hydropower plant = 665.3GWh ; Imports = 2278GWh<br>Total cost : **2443M$**<br>Levelized cost of energy : **0.080$/kWh** | Its interconnection with Benin, leads to the same imports. The hydrological conditions in Togo seem to be able to provide more electrical energy than in Benin because less installed capacity, the energy produced represents 10% of the total production, which remains nevertheless little. |
| Burkina Faso | Demand : 1612.2GWh<br>Load power : 334MW<br>Existing fleet : Hydropower plant = 2MW ; Thermal power plant = 228MW<br>Imports : Ivory Coast 50MW<br>Decided projects : Generators 7.5 & 50MW (2018, 2020) ; Hydropower plant 2.76MW (2019)<br>Planned projects : Generators ; 5 Hydropower plant 60MW<br>**Available energy** : Thermal power plant = 1254.6GWh ; Hydropower plant = 7GWh ; Imports = 350.4GWh<br>Candidates power plant : HFO1, CC6, CC2 & OCGT9 | Demand : 8230.4GWh<br>Load power : 1708.2MW<br>Existing fleet : Hydropower plant = 0MW ; Thermal power plant = 84.5MW<br>Imports : Ivory Coast 150MW<br>Planned projects : Thermal power plant = 160MW ; Hydropower plant 47.1MW<br>Candidates power plant : 2 CC2, 12 CC6 & 2 OCGT9<br>**Available energy** : Thermal power plant = 6993GWh ; Hydropower plant = 186.2GWh ; Imports = 1051GWh<br>Total cost : **3995M$**<br>Levelized cost of energy : **0.118$/kWh** | The total cost is significant because of the generator projects. The fuels used in Burkina Faso are HFO and DDO, which have high costs, as well as the power plants using them. The country's hydraulic potential is low: only 2% of the energy produced. |
| Niger | Demand : 1150.9GWh<br>Load power : 215.4MW<br>Existing fleet : Thermal power plant = 151.4MW<br>Imports : Nigeria 40MW<br>Decided projects :  Coal power plant 68.8MW (2018) ; Generators 4.5 & 20MW (2018, 2020) ; Hydropower plant 130MW (2021)<br>Planned projects : Coal power plant ; 2 Hydropower plant 130MW<br>**Available energy** : Thermal power plant = 870.5GWh; Hydropower plant = 0GWh ; Imports = 280.3GWh<br>Candidates power plant : OCGT8, COAL10 & DDO1 | Demand : 7663.1GWh<br>Load power : 1434.4MW<br>Existing fleet : Hydropower plant = 0MW ; Thermal power plant = 112.8MW<br>Imports : Nigeria 120MW<br>Planned projects : Thermal power plant = 600MW ; Hydropower plant = 131MW<br>Candidates power plant : 3 COAL10, 2 DDO1 & 4 OCGT8<br>**Available energy** : Thermal power plant = 6267.5GWh ; Hydropower plant = 554.7GWh ; Imports = 841GWh<br>Total cost : **2527M$**<br>Levelized cost of energy : **0.093$/kWh** | Niger continues to import from Nigeria with an increase in the capacity of the line between the two countries. Niger is turning to coal power plants, still uses DDO fuel oil and imports its gas from Nigeria, which does not necessarily mean a high total cost but expensive production. |

*Table 32 : Results for the self-sufficient strategy for import countries in the Eastern zone of the ECOWAS*

| | | | |
|---|---|---|---|
| Ghana | Demand : 13891.1GWh<br>Load power : 2127.8MW<br>Existing fleet : Thermal power plant = 2786MW ; Hydropower plant = 1386MW<br>Exports : Togo & Benin 25MW<br>Decided projects : Combined cycle 630, 560 & 330MW (2018, 2019 & 2022)<br>Planned projects : Coal power plant 700MW ; 2 Combined cycle 210MW & 5 Hydropower plant 307MW<br>**Available energy** : Thermal power plant = 9034.7GWh ; Hydroelectricity = 4856.4GWh<br>Candidate power plant : OCGT8, CC4 & NGCC | Demand : 48988.7GWh<br>Load power : 7504.0MW<br>Existing fleet : Thermal power plant = 1421MW ; Hydropower plant = 1242MW<br>Exports : Togo & Benin 25MW<br>Planned projects : Coal power plant = 700MW ; Combined cycle = 100MW ; Hydropower plant = 91MW<br>Candidate power plant : 2 CC4, 4 NGCC & 3 OCGT8<br>**Available energy** : Thermal power plant = 43290.1; Hydroelectricity = 4729.8GWh<br>Total cost : **16385M$**<br>Levelized cost of energy : **0.057$/kWh** | In 2018, the installed capacity is 40% greater than the Demand's capacity, but the transmission and distribution system is of poor quality[28]. As almost all of the hydraulic potential is used, with Sankofa[29] the local gas production is reserved for the production of electricity from the thermal projects decided and planned. Similarly, the candidate projects are based on a division between Combined Cycle power plants and gas turbines. |
| Côte d'Ivoire | Demand : 9357.5GWh<br>Load power : 1463.3MW<br>Existing fleet : Thermal power plant = 1131.5MW ; Hydropower plant = 829.8MW<br>Exports : Burkina Faso 50MW ; Mali 70MW<br>Decided projects : Combined cycle 440 & 230MW (2020, 2021) ; Hydropower plant 156MW (2022)<br>Planned projects : Coal power plant 700MW ; 6 Combined cycle 738MW & 7 Hydropower plant 785MW<br>**Available energy** : Thermal power plant = 6413GWh ; Hydroelectricity = 2927GWh<br>Candidate power plant : OCGT8, CC4 & NGCC | Demand : 40613.3GWh<br>Load power : 6350.9MW<br>Existing fleet : Thermal power plant = 111MW ; Hydropower plant = 279MW<br>Exports : Burkina Faso 150MW ; Mali 70MW<br>Planned projects : Combined cycle = 738MW ; Hydropower plant = 644MW<br>Candidate power plant : 3 CC4, 4 NGCC & 3 OCGT8<br>**Available energy** : Thermal power plant = 33768.3GWh ; Hydroelectricity = 6845GWh<br>Total cost : **13220M$**<br>Levelized cost of energy : **0.055$/kWh** | In view of the outlook for the fleet's development, the candidate projects are based on high-power combined cycles. Local gas production dedicated to electricity[30]. Extension of capacity to export to Burkina Faso. Use of hydraulic potential. In 2040, Ivory Coast's role is even more important.<br>In self-sufficient strategy it has the cheapest electricity in the Eastern zone. |
| Nigeria | Demand : 54907GWh<br>Load power : 9131.7MW<br>Existing fleet : Thermal power plant = 7354MW ; Hydropower plant = 1216MW<br>Exports : Togo & Benin 100MW ; Niger 40MW<br>Decided projects : Combined cycle 339, 441, 285MW (2018, 2019, 2025) ; Hydropower plant 30MW (2018)<br>Planned projects : Coal power plant 6464MW ; 4 Hydropower plant 3829MW ; Combined cycle and Gas turbines are represented by Candidate power plant<br>**Available energy** : Thermal power plant = 47273GWh ; Hydroelectricity = 4260GWh ;<br>Candidate power plant : CC4, NGCC, OCGT9 & COAL11 | Demand : 365607.8GWh<br>Load power : 60804.3MW<br>Existing fleet : Thermal power plant = 113MW ; Hydropower plant = 0MW<br>Exports : Togo & Benin 150MW ; Niger 120MW<br>Planned projects : Combined cycle & Gas turbines cf *Candidate power plant* ; Hydropower plant = 3050MW<br>Candidate power plant : 28 CC4, 63 NGCC, 26 OCGT9 & 10 COAL11<br>**Available energy** : Thermal power plant = 351364.5GWh; Hydroelectricity = 14243.3GWh<br>Total cost : **70156M$**<br>Levelized cost of energy : **0.060$/kWh** | Nigeria is a major producer of natural gas, it makes this resource a priority and turns its fleet towards Combined Cycle and gas turbines. To meet its energy needs (76% of the Eastern zone's energy demand), the Total cost is very important. As the share of hydropower is very low (4% of the energy produced), the Levelized cost of energy is higher than for Ghana and Ivory Coast. Faced with the country's current situation, represented by a high interest rate of 9%, Nigeria needs a lot of investment to meet the growth of its demand. |

*Table 33 : Results for the self-sufficient strategy for export countries in the Eastern zone of the ECOWAS*

[28] (Center of Global Development, 2017)
[29] (Agence ECOFIN, 2018)
[30] (Jeune Afrique, 2018)

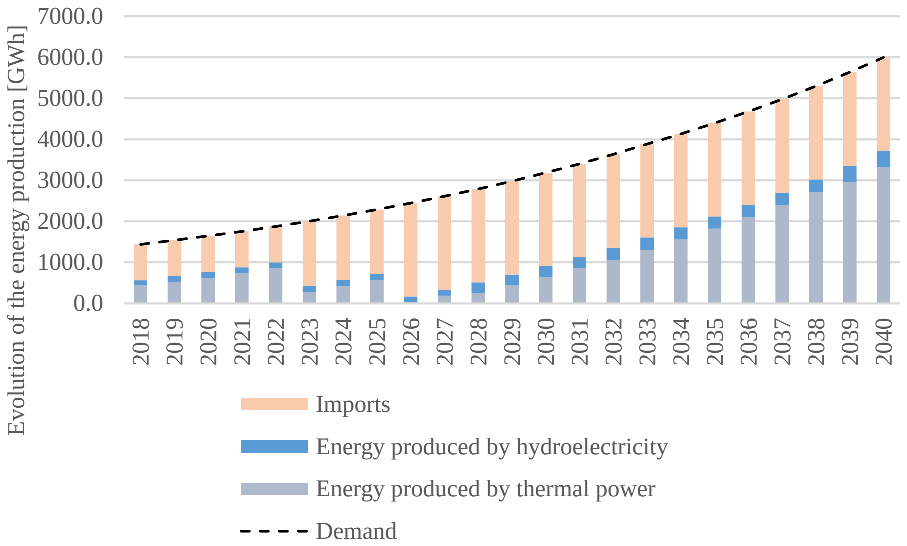


*Figure 31 : Evolution of the energy production by production type in Benin*

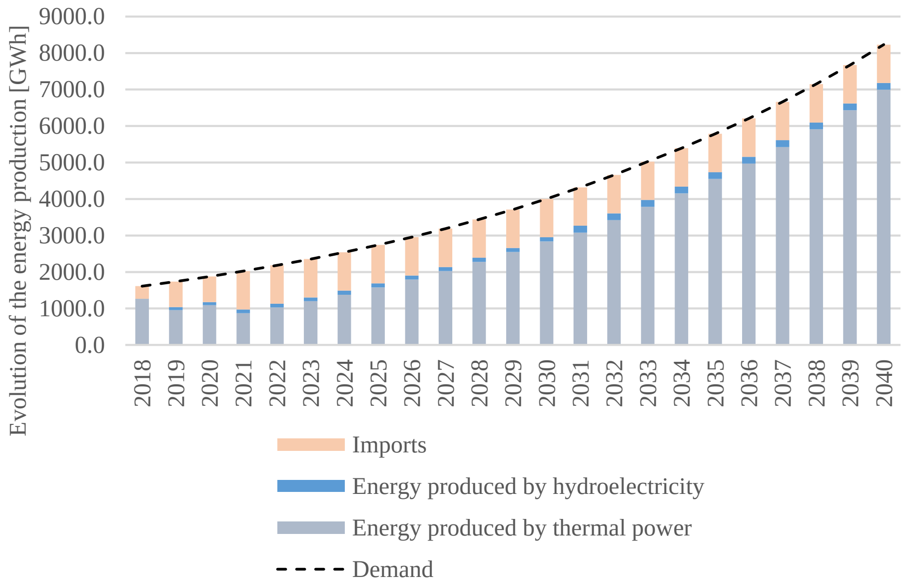


*Figure 33 : Evolution of the energy production by production type in Burkina Faso*

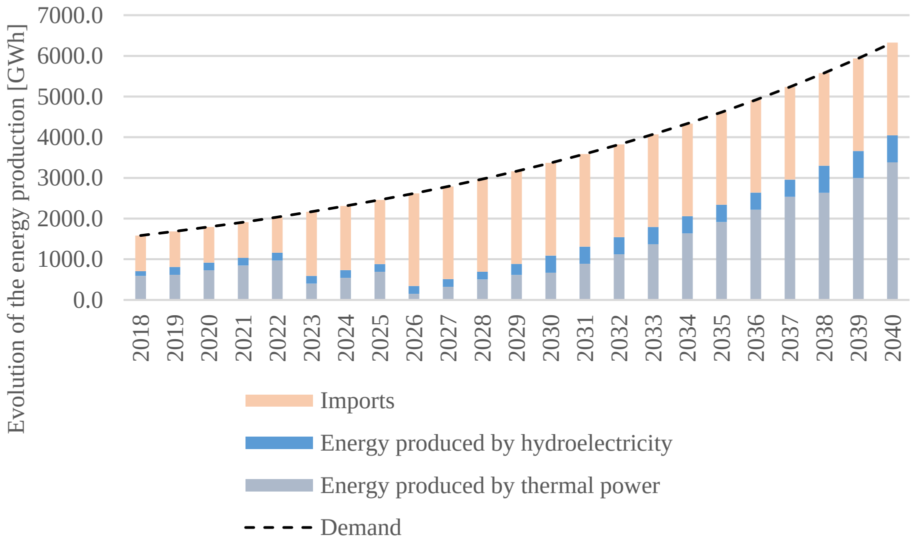


*Figure 32 : Evolution of the energy production by production type in Togo*

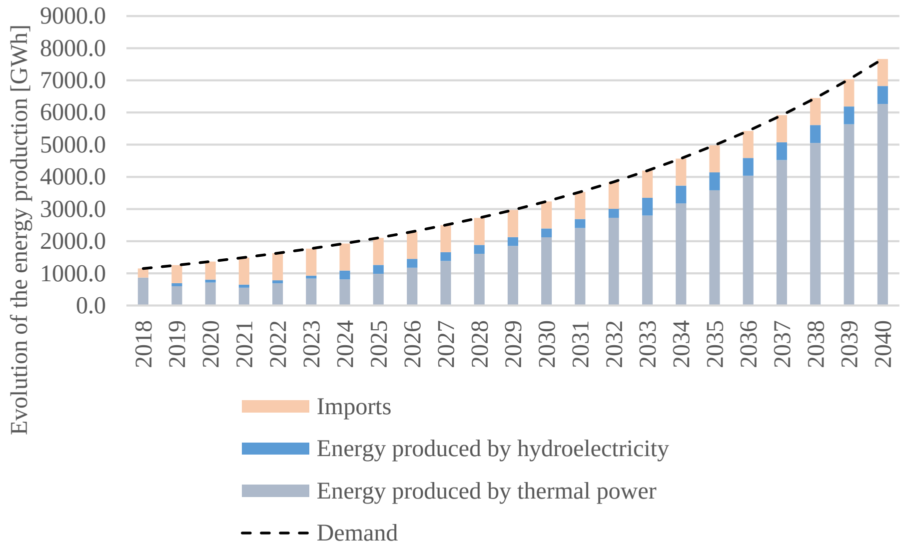


*Figure 34 : Evolution of the energy production by production type in Niger*

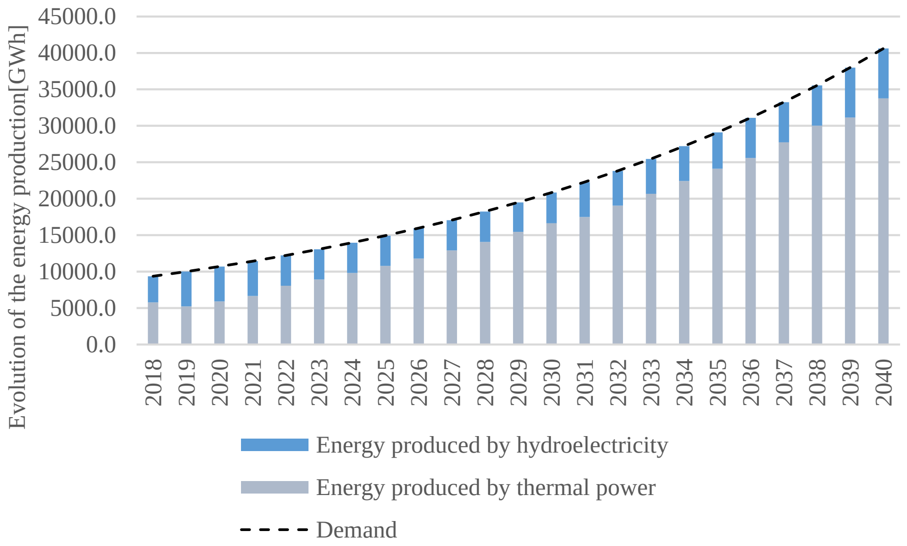


*Figure 35 : Evolution of the energy production by production type in Ivory Coast*

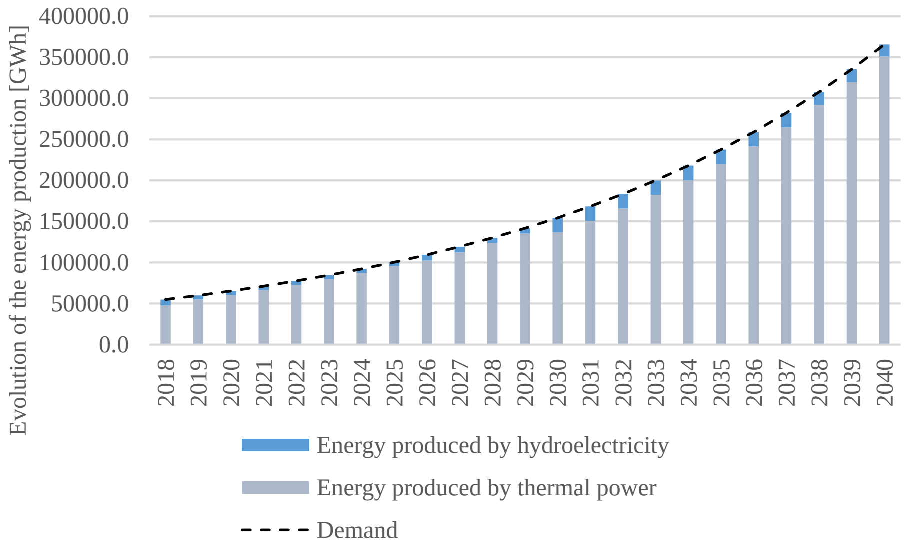


*Figure 37 : Evolution of the energy production by production type in Nigeria*

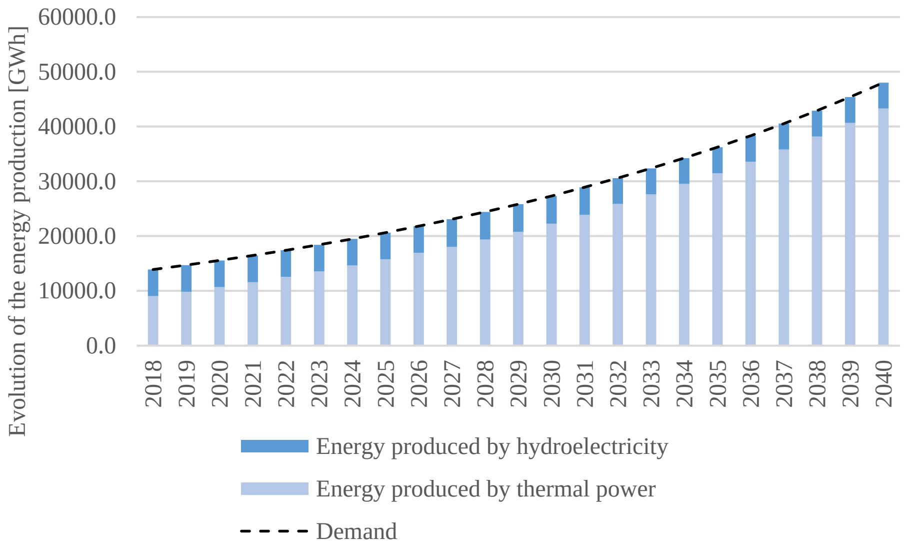


*Figure 36 : Evolution of the energy production by production type in Ghana*

| Countries | Demand [GWh] | Thermal power [MW] | Thermal energy [GWh] | Hydropower [MW] | Hydraulic energy [GWh] | Total energy [GWh] | Importation (<0) Exportation (>0) | Local production share |
|---|---|---|---|---|---|---|---|---|
| Benin | 1309.3 | 63.0 | 0.0 | 32.5 | 0.0 | 0.0 | -1309.3 | 0% |
| Burkina | 1612.2 | 215.8 | 0.0 | 0.0 | 0.0 | 0.0 | -1612.2 | 0% |
| Ivory Coast | 9357.5 | 1236.5 | 7100.8 | 829.8 | 2908.2 | 10009.0 | 651.5 | 107% |
| Gambia | 393.7 | 89.8 | 0.0 | 0.0 | 0.0 | 0.0 | -393.7 | 0% |
| Ghana | 13891.1 | 3266.0 | 8906.0 | 1579.9 | 4858.0 | 13764.0 | -127.1 | 99% |
| Guinea | 1349.4 | 141.8 | 0.0 | 67.0 | 1396.2 | 1396.2 | 46.8 | 103% |
| Guinea Bissau | 168.2 | 37.0 | 0.0 | 0.0 | 0.0 | 0.0 | -168.2 | 0% |
| Liberia | 372.6 | 48.0 | 0.0 | 88.0 | 308.0 | 308.0 | -64.6 | 83% |
| Mali | 2060.1 | 118.9 | 0.0 | 184.4 | 872.0 | 872.0 | -1188.1 | 42% |
| Niger | 1150.9 | 161.4 | 463.2 | 0.0 | 0.0 | 463.2 | -687.7 | 40% |
| Nigeria | 54907.6 | 11179.0 | 56088.2 | 1726.0 | 4260.0 | 60348.2 | 5440.6 | 110% |
| Senegal | 2961.8 | 951.4 | 3458.9 | 78.9 | 334.0 | 3792.9 | 831.1 | 128% |
| Sierra Leone | 490.0 | 87.0 | 0.0 | 45.0 | 200.0 | 200.0 | -290.0 | 41% |
| Togo | 1582.5 | 114.0 | 0.1 | 32.5 | 227.8 | 227.9 | -1354.6 | 14% |

*Table 34 : Review of the installed power and the energy produced in 2018*

| Countries | Demand [GWh] | Thermal power [MW] | Thermal energy [GWh] | Hydropower [MW] | Hydraulic energy [GWh] | Total energy [GWh] | Importation (<0) Exportation (>0) | Local production part |
|---|---|---|---|---|---|---|---|---|
| Benin | 5451.2 | 200.0 | 488.8 | 191.2 | 219.0 | 707.8 | -4743.4 | 13% |
| Burkina | 8230.4 | 134.5 | 1.6 | 37.0 | 148.0 | 149.6 | -8080.8 | 2% |
| Ivory Coast | 40613.3 | 7702.0 | 38980.6 | 1176.0 | 6804.0 | 45784.6 | 5171.3 | 113% |
| Gambia | 2527.9 | 51.8 | 1.7 | 36.4 | 77.4 | 79.1 | -2448.8 | 3% |
| Ghana | 48019.9 | 11285.0 | 48040.8 | 1726.9 | 5642.6 | 53683.4 | 5663.5 | 112% |
| Guinea | 8200.5 | 21.0 | 0.0 | 2779.4 | 12574.8 | 12574.8 | 4374.3 | 153% |
| Guinea Bissau | 1931.8 | 37.0 | 0.6 | 44.2 | 133.6 | 134.2 | -1797.6 | 7% |
| Liberia | 3786.2 | 48.0 | 1.4 | 654.0 | 1896.5 | 1897.9 | -1888.3 | 50% |
| Mali | 9213.3 | 142.0 | 3.9 | 518.9 | 1868.9 | 1872.8 | -7340.5 | 20% |
| Niger | 7663.1 | 218.8 | 821.1 | 261.0 | 915.0 | 1736.1 | -5927.0 | 23% |
| Nigeria | 365607.8 | 59899.0 | 370597.0 | 3829.0 | 14510.0 | 385107.0 | 19499.1 | 105% |
| Senegal | 19295.4 | 4465.0 | 19371.1 | 464.2 | 1643.1 | 21014.1 | 1718.7 | 109% |
| Sierra Leone | 3192.3 | 87.0 | 1.8 | 881.0 | 4538.5 | 4540.3 | 1348.0 | 142% |
| Togo | 6324.7 | 130.0 | 4.1 | 0.0 | 0.0 | 4.1 | -6320.6 | 0% |

*Table 35 : Review of the installed power and the energy produced in 2040*

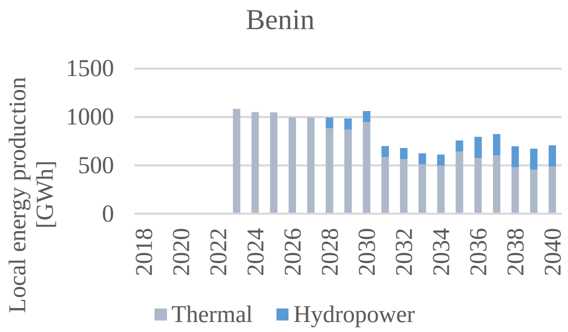


*Figure 38 : Local energy production for Benin*

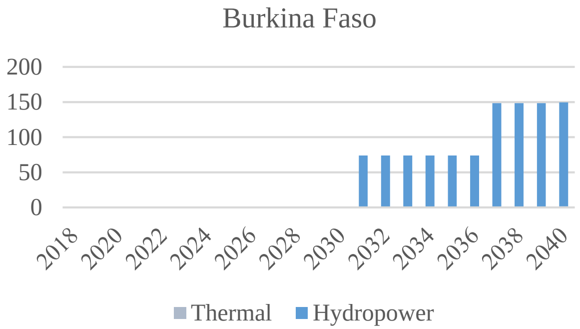


*Figure 39 : Local energy production for Burkina Faso*

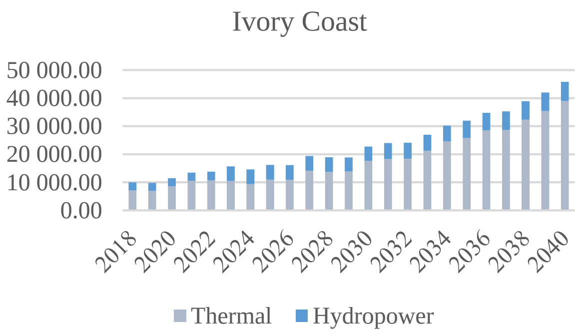


*Figure 40 : Local energy production for Ivory Coast*

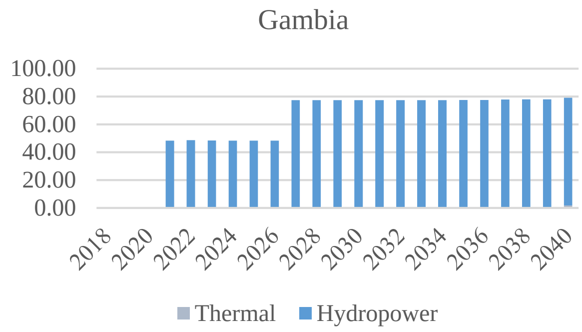


*Figure 41 : Local energy production for Gambia*

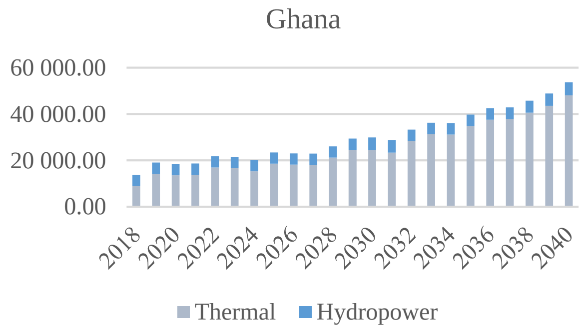


*Figure 42 : Local energy production for Ghana*

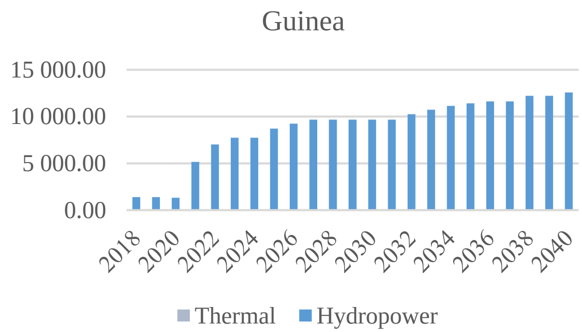


*Figure 43 : Local energy production for Guinea*

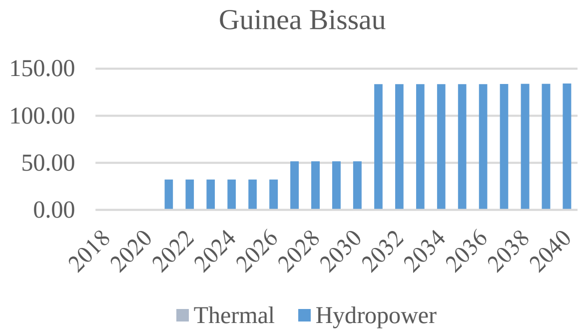


*Figure 44 : Local energy production for Guinea Bissau*

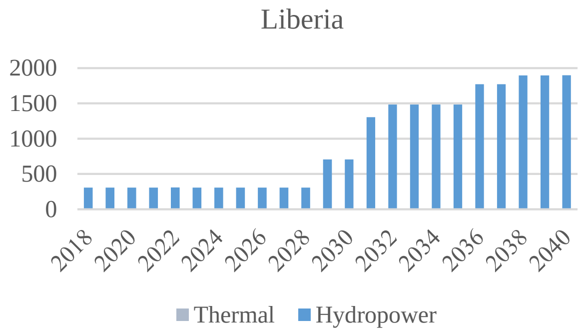


*Figure 45 : Local energy production for Liberia*

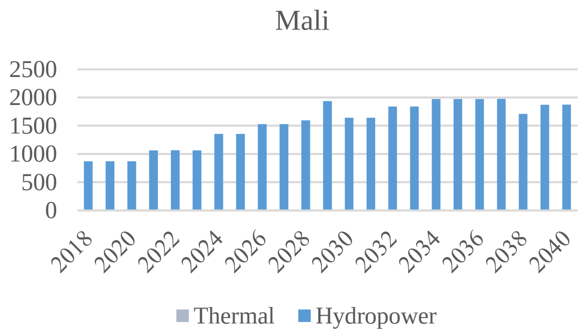


*Figure 46 : Local energy production for Mali*

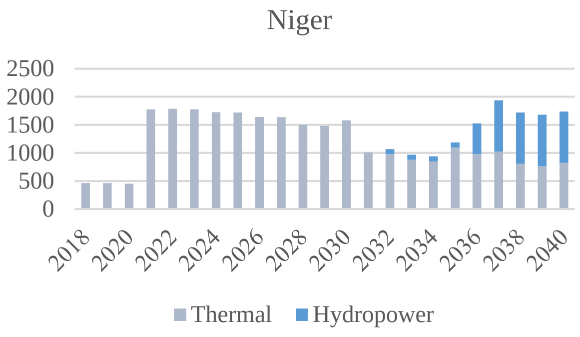


*Figure 47 : Local energy production for Niger*

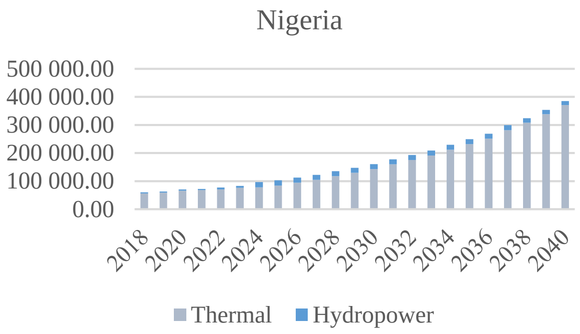


*Figure 48 : Local energy production for Nigeria*

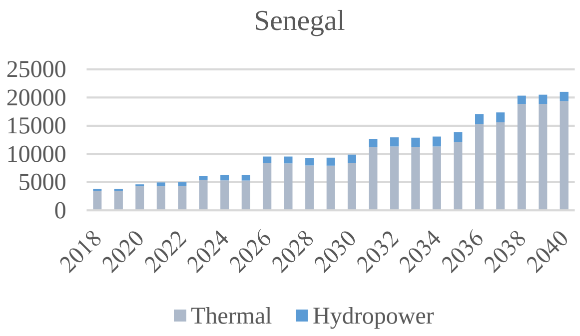


*Figure 49 : Local energy production for Senegal*

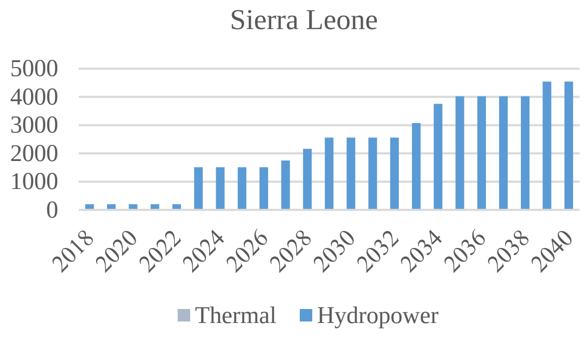


*Figure 50 : Local energy production for Sierra Leone*

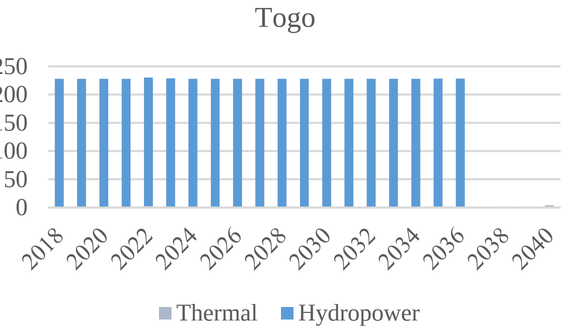


*Figure 51 : Local energy production for Togo*

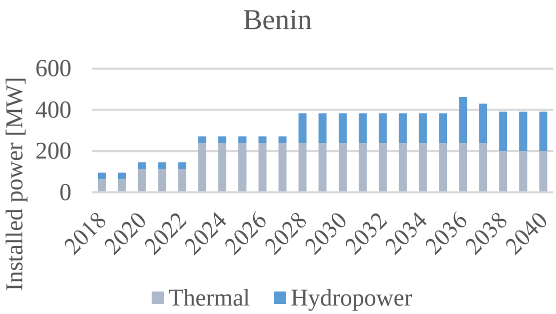


*Figure 52 : Installed power in Benin*

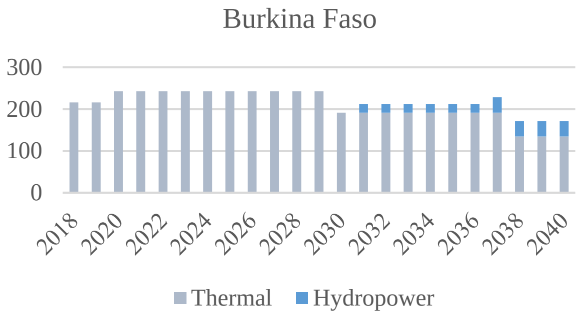


*Figure 53 : Installed power in Burkina Faso*

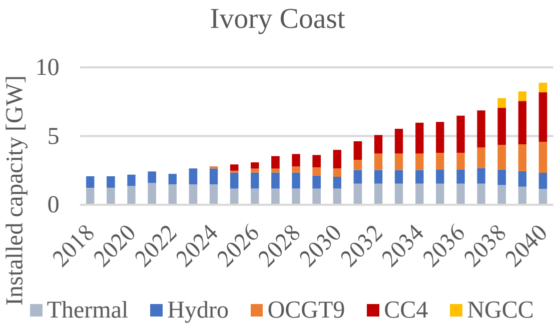


*Figure 54 : Installed power in Ivory Coast*

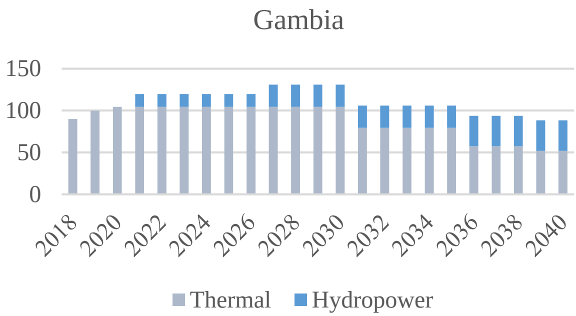


*Figure 55 : Installed power in Gambia*

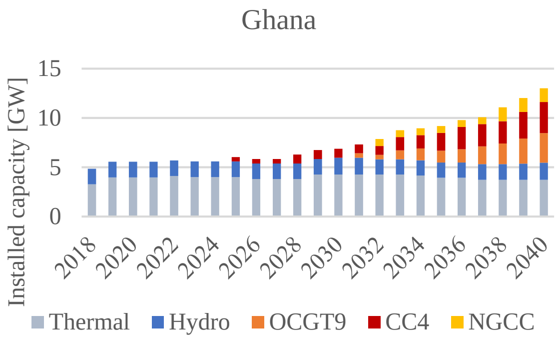


*Figure 56 : Installed power in Ghana*

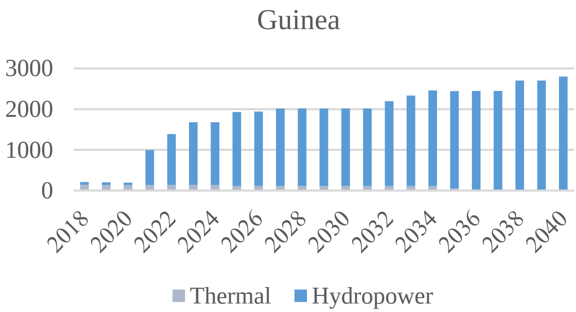


*Figure 57 : Installed power in Guinea*

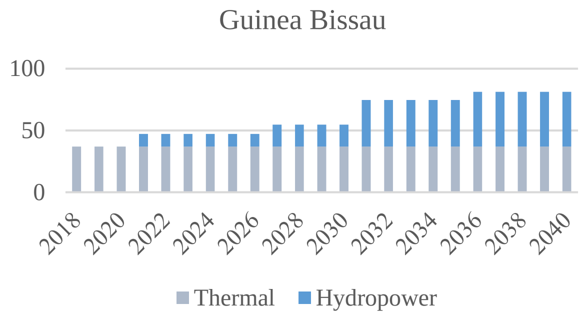


*Figure 58 : Installed power in Guinea Bissau*

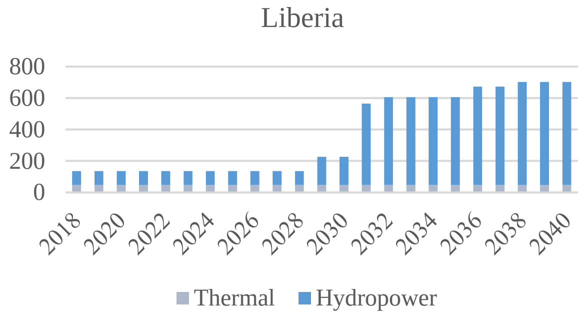


*Figure 59 : Installed power in Liberia*

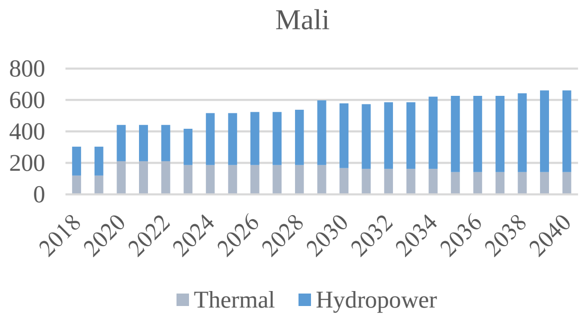


*Figure 60 : Installed power in Mali*

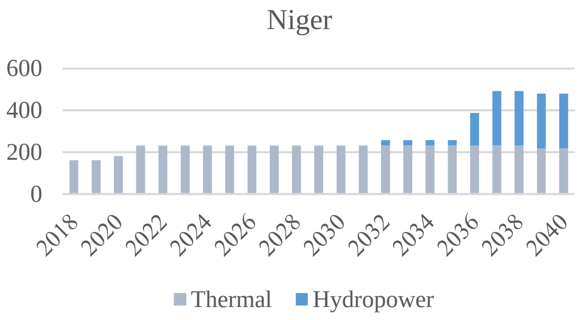


*Figure 61 : Installed power in Niger*

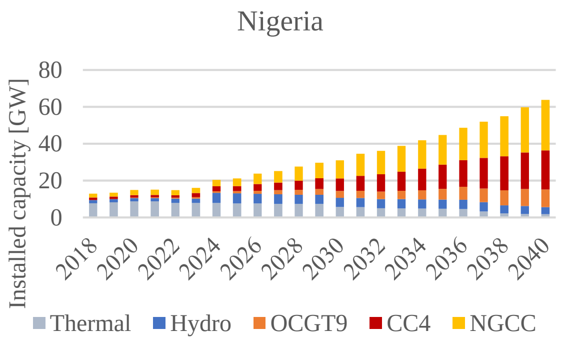


*Figure 62 : Installed power in Nigeria*

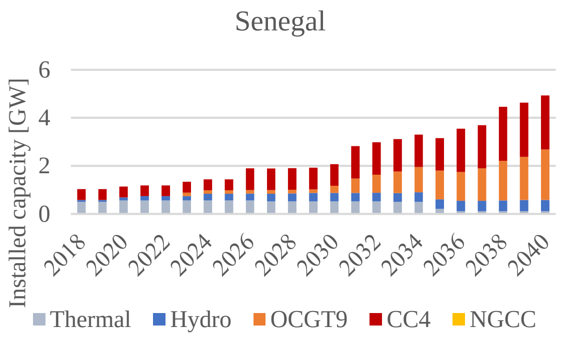


*Figure 63 : Installed power in Senegal*

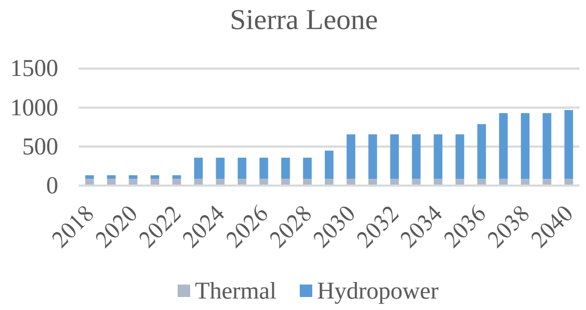


*Figure 64 : Installed power in Sierra Leone*

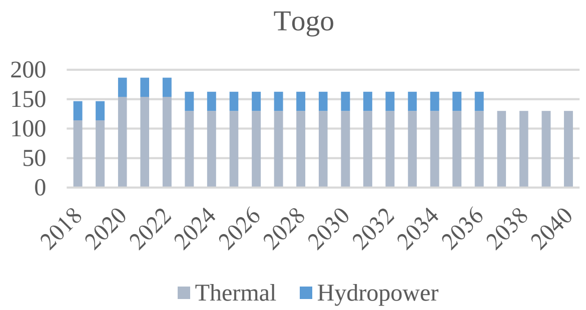


*Figure 65 : Installed power in Togo*

| 2018 | Benin | Burkina Faso | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermal prod. | 0.0 | 0.0 | 7100.8 | 0.0 | 8906.0 | 0.0 | 0.0 | 0.0 | 0.0 | 463.2 | 56088.2 | 3458.9 | 0.0 | 0.1 | 76017.2 |
| Hydro prod. | 0.0 | 0.0 | 2908.2 | 0.0 | 4858.0 | 1396.2 | 0.0 | 308.0 | 872.0 | 0.0 | 4260.0 | 334.0 | 200.0 | 227.8 | 15364.2 |
| Demand | 1309.3 | 1612.2 | 9357.5 | 393.7 | 13891.1 | 1349.4 | 168.2 | 372.6 | 2060.1 | 1150.9 | 54907.6 | 2961.8 | 490.0 | 1582.5 | 91606.9 |
| Local share of energy | 0.0 | 0.0 | 1.1 | 0.0 | 1.0 | 1.0 | 0.0 | 0.8 | 0.4 | 0.4 | 1.1 | 1.3 | 0.4 | 0.1 | |
| Quantity of exporting energy | -1309.3 | -1612.2 | 651.5 | -393.7 | -127.1 | 46.8 | -168.2 | -64.6 | -1188.1 | -687.7 | 5440.6 | 831.1 | -290.0 | -1354.6 | |

| 2019 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermal prod. | 0.0 | 0.0 | 6898.6 | 0.0 | 14194.9 | 0.1 | 0.0 | 0.0 | 0.0 | 463.6 | 59032.8 | 3459.0 | 0.0 | 0.1 | 84049.1 |
| Hydro prod. | 0.0 | 0.0 | 2908.2 | 0.0 | 4858.0 | 1396.2 | 0.0 | 308.0 | 872.0 | 0.0 | 4260.0 | 334.0 | 200.0 | 227.8 | 15364.2 |
| Demand | 1398.8 | 1739.2 | 10003.1 | 455.9 | 14696.8 | 1565.2 | 217.7 | 444.7 | 2385.0 | 1254.4 | 59849.3 | 3390.7 | 561.0 | 1685.4 | 99647.4 |
| Local share of energy | 0.0 | 0.0 | 1.0 | 0.0 | 1.3 | 0.9 | 0.0 | 0.7 | 0.4 | 0.4 | 1.1 | 1.1 | 0.4 | 0.1 | |
| Quantity of exporting energy | -1398.8 | -1739.2 | -196.3 | -455.9 | 4356.1 | -168.9 | -217.7 | -136.7 | -1513.0 | -790.8 | 3443.5 | 402.3 | -361.0 | -1457.5 | |

| 2020 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermal prod. | 0.1 | 0.0 | 8573.0 | 0.0 | 13595.4 | 0.0 | 0.0 | 0.0 | 0.0 | 452.7 | 65964.8 | 4272.6 | 0.0 | 0.1 | 92858.7 |
| Hydro prod. | 0.0 | 0.0 | 2908.2 | 0.0 | 4858.0 | 1323.8 | 0.0 | 308.0 | 872.0 | 0.0 | 4260.0 | 334.0 | 200.0 | 227.8 | 15291.8 |
| Demand | 1494.5 | 1876.1 | 10693.4 | 528.0 | 15549.2 | 1815.5 | 281.9 | 530.8 | 2761.2 | 1367.3 | 65235.7 | 3881.8 | 642.2 | 1794.9 | 108452.5 |
| Local share of energy | 0.0 | 0.0 | 1.1 | 0.0 | 1.2 | 0.7 | 0.0 | 0.6 | 0.3 | 0.3 | 1.1 | 1.2 | 0.3 | 0.1 | |
| Quantity of exporting energy | -1494.4 | -1876.1 | 787.8 | -528.0 | 2904.2 | -491.7 | -281.9 | -222.8 | -1889.2 | -914.6 | 4989.1 | 724.8 | -442.2 | -1567.0 | |

| 2021 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermal prod. | 0.1 | 0.0 | 10544.2 | 0.0 | 13795.6 | 0.1 | 0.0 | 0.0 | 0.1 | 1776.3 | 68028.3 | 4278.0 | 0.0 | 0.2 | 98422.9 |
| Hydro prod. | 0.0 | 0.0 | 2908.2 | 48.2 | 4858.0 | 5151.6 | 32.2 | 308.0 | 1064.1 | 0.0 | 4260.0 | 681.3 | 200.0 | 227.8 | 19739.4 |
| Demand | 1596.6 | 2023.9 | 11431.2 | 611.4 | 16451.1 | 2105.8 | 364.9 | 633.6 | 3196.7 | 1490.4 | 71106.9 | 4444.0 | 735.2 | 1911.6 | 118103.4 |
| Local share of energy | 0.0 | 0.0 | 1.2 | 0.1 | 1.1 | 2.4 | 0.1 | 0.5 | 0.3 | 1.2 | 1.0 | 1.1 | 0.3 | 0.1 | |
| Quantity of exporting energy | -1596.5 | -2023.9 | 2021.2 | -563.2 | 2202.5 | 3045.9 | -332.7 | -325.6 | -2132.5 | 285.9 | 1181.4 | 515.2 | -535.2 | -1683.6 | |

| 2022 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermal prod. | 1.2 | 0.0 | 10680.7 | 0.4 | 16920.1 | 1.3 | 0.1 | 0.4 | 1.2 | 1784.0 | 70164.5 | 4284.9 | 0.3 | 2.5 | 103841.6 |
| Hydro prod. | 0.0 | 0.0 | 3123.2 | 48.2 | 4858.0 | 7025.6 | 32.2 | 308.0 | 1064.1 | 0.0 | 7279.0 | 681.3 | 200.0 | 227.8 | 24847.4 |
| Demand | 1705.8 | 2183.2 | 12220.0 | 708.0 | 17405.2 | 2442.6 | 472.4 | 756.2 | 3700.9 | 1624.5 | 77506.6 | 5087.6 | 841.7 | 2035.9 | 128690.6 |
| Local share of energy | 0.0 | 0.0 | 1.1 | 0.1 | 1.3 | 2.9 | 0.1 | 0.4 | 0.3 | 1.1 | 1.0 | 1.0 | 0.2 | 0.1 | |
| Quantity of exporting energy | -1704.6 | -2183.2 | 1583.9 | -659.4 | 4372.9 | 4584.3 | -440.1 | -447.8 | -2635.6 | 159.5 | -63.1 | -121.5 | -641.4 | -1805.6 | |

| 2023 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermal prod. | 1084.4 | 0.0 | 10473.8 | 0.2 | 16705.1 | 0.6 | 0.1 | 0.2 | 0.6 | 1776.7 | 75900.1 | 5381.4 | 0.1 | 1.0 | 111324.3 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydro prod. | 0.0 | 0.0 | 5238.2 | 48.2 | 4858.0 | 7745.6 | 32.2 | 308.0 | 1064.1 | 0.0 | 7279.0 | 681.3 | 1510.0 | 227.8 | 28992.4 |
| Demand | 1822.5 | 2355.2 | 13063.1 | 819.9 | 18414.7 | 2833.2 | 611.5 | 902.6 | 4284.5 | 1770.7 | 84482.2 | 5824.5 | 963.6 | 2168.2 | 140316.5 |
| Local share of energy | 0.6 | 0.0 | 1.2 | 0.1 | 1.2 | 2.7 | 0.1 | 0.3 | 0.2 | 1.0 | 1.0 | 1.0 | 1.6 | 0.1 | |
| Quantity of exporting energy | -738.1 | -2355.2 | 2648.9 | -771.4 | 3148.4 | 4913.0 | -579.3 | -594.4 | -3219.8 | 6.0 | -1303.1 | 238.2 | 546.5 | -1939.4 | |
| 2024 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 1050.8 | 0.0 | 9382.3 | 0.0 | 15262.2 | 0.0 | 0.0 | 0.0 | 0.0 | 1725.0 | 77946.9 | 5310.3 | 0.0 | 0.0 | 110677.5 |
| Hydro prod. | 0.0 | 0.0 | 5238.2 | 48.2 | 4858.0 | 7745.6 | 32.2 | 308.0 | 1355.8 | 0.0 | 18493.0 | 964.4 | 1510.0 | 227.8 | 40781.2 |
| Demand | 1947.1 | 2540.6 | 13964.5 | 876.0 | 19482.8 | 3015.9 | 654.4 | 982.1 | 4481.9 | 1930.1 | 92085.6 | 6249.7 | 1034.0 | 2309.1 | 151553.7 |
| Local share of energy | 0.5 | 0.0 | 1.0 | 0.1 | 1.0 | 2.6 | 0.0 | 0.3 | 0.3 | 0.9 | 1.0 | 1.0 | 1.5 | 0.1 | |
| Quantity of exporting energy | -896.3 | -2540.6 | 656.1 | -827.8 | 637.4 | 4729.7 | -622.2 | -674.1 | -3126.1 | -205.1 | 4354.4 | 25.0 | 476.0 | -2081.3 | |
| 2025 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 1048.3 | 0.0 | 10937.0 | 0.0 | 18601.9 | 0.0 | 0.0 | 0.0 | 0.0 | 1720.2 | 84182.0 | 5298.9 | 0.0 | 0.0 | 121788.4 |
| Hydro prod. | 0.0 | 0.0 | 5238.2 | 48.2 | 4858.0 | 8719.6 | 32.2 | 308.0 | 1355.8 | 0.0 | 18493.0 | 964.4 | 1510.0 | 227.8 | 41755.2 |
| Demand | 2080.2 | 2740.7 | 14928.0 | 936.0 | 20612.8 | 3210.5 | 700.2 | 1068.5 | 4688.4 | 2103.8 | 100373.3 | 6705.9 | 1109.4 | 2459.2 | 163716.9 |
| Local share of energy | 0.5 | 0.0 | 1.1 | 0.1 | 1.1 | 2.7 | 0.0 | 0.3 | 0.3 | 0.8 | 1.0 | 0.9 | 1.4 | 0.1 | |
| Quantity of exporting energy | -1031.9 | -2740.7 | 1247.2 | -887.8 | 2847.1 | 5509.1 | -668.0 | -760.5 | -3332.6 | -383.6 | 2301.8 | -442.6 | 400.6 | -2231.4 | |
| 2026 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 995.7 | 0.0 | 10935.4 | 0.0 | 18184.6 | 0.0 | 0.0 | 0.0 | 0.0 | 1640.9 | 94304.5 | 8417.4 | 0.0 | 0.0 | 134478.5 |
| Hydro prod. | 0.0 | 0.0 | 5238.2 | 48.2 | 4858.0 | 9247.6 | 32.2 | 308.0 | 1528.9 | 0.0 | 18038.0 | 1132.4 | 1510.0 | 227.8 | 42169.2 |
| Demand | 2222.4 | 2956.5 | 15958.1 | 1000.1 | 21808.3 | 3417.6 | 749.2 | 1162.5 | 4904.4 | 2293.2 | 109406.8 | 7195.4 | 1190.4 | 2619.1 | 176884.1 |
| Local share of energy | 0.4 | 0.0 | 1.0 | 0.0 | 1.1 | 2.7 | 0.0 | 0.3 | 0.3 | 0.7 | 1.0 | 1.3 | 1.3 | 0.1 | |
| Quantity of exporting energy | -1226.7 | -2956.5 | 215.5 | -951.9 | 1234.3 | 5830.0 | -717.0 | -854.5 | -3375.5 | -652.3 | 2935.6 | 2354.3 | 319.6 | -2391.3 | |
| 2027 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 994.8 | 0.0 | 14177.6 | 0.0 | 18118.5 | 0.0 | 0.0 | 0.0 | 0.0 | 1638.4 | 104511.6 | 8319.4 | 0.0 | 0.0 | 147760.3 |
| Hydro prod. | 0.0 | 0.0 | 5238.2 | 77.4 | 4858.0 | 9666.8 | 51.6 | 308.0 | 1528.9 | 0.0 | 18038.0 | 1229.6 | 1747.0 | 227.8 | 42971.2 |
| Demand | 2374.4 | 3189.3 | 17059.2 | 1068.6 | 23073.2 | 3638.1 | 801.6 | 1264.8 | 5130.3 | 2499.6 | 119253.5 | 7720.7 | 1277.3 | 2789.3 | 191139.9 |
| Local share of energy | 0.4 | 0.0 | 1.1 | 0.1 | 1.0 | 2.7 | 0.1 | 0.2 | 0.3 | 0.7 | 1.0 | 1.2 | 1.4 | 0.1 | |
| Quantity of exporting energy | -1379.6 | -3189.3 | 2356.7 | -991.2 | -96.7 | 6028.7 | -750.0 | -956.8 | -3601.4 | -861.2 | 3296.1 | 1828.2 | 469.7 | -2561.5 | |
| 2028 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 882.0 | 0.0 | 13707.4 | 0.0 | 21223.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1499.4 | 117625.2 | 7956.7 | 0.0 | 0.0 | 162893.7 |
| Hydro prod. | 114.0 | 0.0 | 5238.2 | 77.4 | 4858.0 | 9666.8 | 51.6 | 308.0 | 1596.5 | 0.0 | 17583.0 | 1295.2 | 2161.0 | 227.8 | 43177.6 |
| Demand | 2536.7 | 3440.5 | 18236.3 | 1141.7 | 24411.5 | 3872.8 | 857.7 | 1376.1 | 5366.6 | 2724.5 | 129986.3 | 8284.3 | 1370.6 | 2970.6 | 206576.3 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Local share of energy | 0.4 | 0.0 | 1.0 | 0.1 | 1.1 | 2.5 | 0.1 | 0.2 | 0.3 | 0.6 | 1.0 | 1.1 | 1.6 | 0.1 | |
| Quantity of exporting energy | -1540.7 | -3440.5 | 709.3 | -1064.3 | 1669.6 | 5794.0 | -806.1 | -1068.1 | -3770.1 | -1225.1 | 5221.9 | 967.6 | 790.4 | -2742.8 | |
| 2029 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 871.5 | 0.0 | 13869.6 | 0.0 | 24566.7 | 0.0 | 0.0 | 0.0 | 0.0 | 1481.7 | 129907.2 | 7917.4 | 0.0 | 0.0 | 178614.1 |
| Hydro prod. | 114.0 | 0.0 | 4992.2 | 77.4 | 4858.0 | 9666.8 | 51.6 | 705.5 | 1934.9 | 0.0 | 17583.0 | 1430.5 | 2558.5 | 227.8 | 44200.3 |
| Demand | 2710.2 | 3711.4 | 19494.6 | 1219.9 | 25827.3 | 4122.7 | 917.8 | 1497.2 | 5613.9 | 2969.7 | 141685.0 | 8889.1 | 1470.6 | 3163.7 | 223293.1 |
| Local share of energy | 0.4 | 0.0 | 1.0 | 0.1 | 1.1 | 2.3 | 0.1 | 0.5 | 0.3 | 0.5 | 1.0 | 1.1 | 1.7 | 0.1 | |
| Quantity of exporting energy | -1724.7 | -3711.4 | -632.8 | -1142.5 | 3597.4 | 5544.1 | -866.2 | -791.7 | -3678.9 | -1488.0 | 5805.2 | 458.8 | 1087.9 | -2935.9 | |
| 2030 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 947.6 | 0.0 | 17686.5 | 0.0 | 24477.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1580.3 | 143086.2 | 8446.6 | 0.0 | 0.0 | 196224.2 |
| Hydro prod. | 114.0 | 0.0 | 5068.0 | 77.4 | 5457.0 | 9666.8 | 51.6 | 705.5 | 1642.9 | 0.0 | 17583.0 | 1430.5 | 2558.5 | 227.8 | 44583.1 |
| Demand | 2895.5 | 4003.7 | 20839.7 | 1303.5 | 27325.3 | 4388.6 | 982.0 | 1629.0 | 5872.5 | 3237.0 | 154436.7 | 9538.0 | 1578.0 | 3369.3 | 241398.8 |
| Local share of energy | 0.4 | 0.0 | 1.1 | 0.1 | 1.1 | 2.2 | 0.1 | 0.4 | 0.3 | 0.5 | 1.0 | 1.0 | 1.6 | 0.1 | |
| Quantity of exporting energy | -1833.9 | -4003.7 | 1914.8 | -1226.1 | 2608.7 | 5278.2 | -930.4 | -923.5 | -4229.5 | -1656.7 | 6232.5 | 339.1 | 980.5 | -3141.5 | |
| 2031 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 584.3 | 0.0 | 18333.6 | 0.0 | 23354.2 | 0.0 | 0.0 | 0.0 | 0.0 | 1010.3 | 159893.5 | 11246.7 | 0.0 | 0.0 | 214422.7 |
| Hydro prod. | 114.0 | 74.0 | 5668.0 | 77.4 | 5457.0 | 9666.8 | 133.6 | 1305.5 | 1642.9 | 0.0 | 17583.0 | 1430.5 | 2558.5 | 227.8 | 45939.1 |
| Demand | 3093.5 | 4319.0 | 22277.6 | 1392.7 | 28910.2 | 4671.8 | 1050.7 | 1772.3 | 6143.0 | 3528.3 | 168336.0 | 10234.3 | 1693.2 | 3588.4 | 261011.0 |
| Local share of energy | 0.2 | 0.0 | 1.1 | 0.1 | 1.0 | 2.1 | 0.1 | 0.7 | 0.3 | 0.3 | 1.1 | 1.2 | 1.5 | 0.1 | |
| Quantity of exporting energy | -2395.2 | -4245.0 | 1724.0 | -1315.3 | -99.0 | 4995.0 | -917.1 | -466.8 | -4500.0 | -2518.0 | 9140.5 | 2443.0 | 865.3 | -3360.6 | |
| 2032 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 565.4 | 0.0 | 18443.7 | 0.0 | 28312.0 | 0.0 | 0.0 | 0.0 | 0.0 | 974.9 | 175196.4 | 11324.4 | 0.0 | 0.0 | 234816.9 |
| Hydro prod. | 114.0 | 74.0 | 5668.0 | 77.4 | 4952.6 | 10256.8 | 133.6 | 1482.5 | 1840.5 | 91.0 | 17583.0 | 1622.3 | 2558.5 | 227.8 | 46681.9 |
| Demand | 3305.0 | 4659.1 | 23814.8 | 1488.1 | 30587.0 | 4973.2 | 1124.3 | 1928.3 | 6426.0 | 3845.9 | 183486.2 | 10981.4 | 1816.8 | 3821.6 | 282257.6 |
| Local share of energy | 0.2 | 0.0 | 1.0 | 0.1 | 1.1 | 2.1 | 0.1 | 0.8 | 0.3 | 0.3 | 1.1 | 1.2 | 1.4 | 0.1 | |
| Quantity of exporting energy | -2625.6 | -4585.1 | 296.9 | -1410.7 | 2677.7 | 5283.6 | -990.7 | -445.8 | -4585.5 | -2780.0 | 9293.2 | 1965.3 | 741.7 | -3593.8 | |
| 2033 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 510.6 | 0.0 | 21286.0 | 0.0 | 31313.0 | 0.0 | 0.0 | 0.0 | 0.0 | 875.6 | 191363.4 | 11262.8 | 0.0 | 0.0 | 256611.5 |
| Hydro prod. | 114.0 | 74.0 | 5668.0 | 77.4 | 4952.6 | 10736.8 | 133.6 | 1482.5 | 1840.5 | 91.0 | 17720.0 | 1622.3 | 3071.5 | 227.8 | 47811.9 |
| Demand | 3531.0 | 5026.0 | 25458.0 | 1590.0 | 32361.0 | 5294.0 | 1203.0 | 2098.0 | 6722.0 | 4192.0 | 200000.0 | 11783.0 | 1949.4 | 4070.0 | 305277.4 |
| Local share of energy | 0.2 | 0.0 | 1.1 | 0.0 | 1.1 | 2.0 | 0.1 | 0.7 | 0.3 | 0.2 | 1.0 | 1.1 | 1.6 | 0.1 | |
| Quantity of exporting energy | -2906.4 | -4952.0 | 1496.0 | -1512.6 | 3904.6 | 5442.8 | -1069.4 | -615.5 | -4881.5 | -3225.4 | 9083.4 | 1102.1 | 1122.1 | -3842.2 | |

| 2034 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermal prod. | 497.2 | 0.0 | 24558.8 | 0.0 | 31161.0 | 0.0 | 0.0 | 0.0 | 0.0 | 848.8 | 211831.5 | 11333.1 | 0.0 | 0.0 | 280230.4 |
| Hydro prod. | 114.0 | 74.0 | 5668.0 | 77.4 | 4952.6 | 11136.8 | 133.6 | 1482.5 | 1974.1 | 91.0 | 17720.0 | 1752.0 | 3751.5 | 227.8 | 49155.3 |
| Demand | 3757.0 | 5392.9 | 27214.6 | 1698.9 | 34237.9 | 5635.5 | 1287.2 | 2282.6 | 7031.7 | 4569.3 | 218000.0 | 12643.2 | 2091.7 | 4334.6 | 330177.0 |
| Local share of energy | 0.2 | 0.0 | 1.1 | 0.0 | 1.1 | 2.0 | 0.1 | 0.6 | 0.3 | 0.2 | 1.1 | 1.0 | 1.8 | 0.1 | |
| Quantity of exporting energy | -3145.8 | -5318.9 | 3012.2 | -1621.5 | 1875.6 | 5501.3 | -1153.6 | -800.1 | -5057.6 | -3629.5 | 11551.5 | 441.9 | 1659.8 | -4106.8 | |
| 2035 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 643.1 | 0.0 | 25788.1 | 0.1 | 34822.0 | 0.1 | 0.0 | 0.1 | 0.2 | 1096.6 | 231539.0 | 12115.2 | 0.1 | 0.3 | 306004.8 |
| Hydro prod. | 114.0 | 74.0 | 6197.0 | 77.4 | 4952.6 | 11417.8 | 133.6 | 1482.5 | 1974.1 | 91.0 | 17720.0 | 1752.0 | 4019.5 | 227.8 | 50233.3 |
| Demand | 3997.4 | 5786.6 | 29092.4 | 1815.2 | 36223.7 | 5999.1 | 1377.3 | 2483.5 | 7355.6 | 4980.5 | 237620.0 | 13566.1 | 2244.4 | 4616.3 | 357158.2 |
| Local share of energy | 0.2 | 0.0 | 1.1 | 0.0 | 1.1 | 1.9 | 0.1 | 0.6 | 0.3 | 0.2 | 1.0 | 1.0 | 1.8 | 0.0 | |
| Quantity of exporting energy | -3240.3 | -5712.6 | 2892.7 | -1737.7 | 3550.8 | 5418.8 | -1243.7 | -1000.9 | -5381.3 | -3792.9 | 11639.0 | 301.0 | 1775.2 | -4388.2 | |
| 2036 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 575.4 | 0.0 | 28549.9 | 0.1 | 37603.9 | 0.0 | 0.0 | 0.1 | 0.2 | 980.2 | 251092.5 | 15315.1 | 0.1 | 0.3 | 334117.8 |
| Hydro prod. | 219.0 | 74.0 | 6197.0 | 77.4 | 4952.6 | 11623.8 | 133.6 | 1771.5 | 1974.1 | 547.0 | 17720.0 | 1752.0 | 4019.5 | 227.8 | 51289.3 |
| Demand | 4253.3 | 6209.0 | 31099.8 | 1939.5 | 38324.7 | 6386.1 | 1473.7 | 2702.0 | 7694.4 | 5428.8 | 259005.8 | 14556.4 | 2408.3 | 4916.4 | 386398.2 |
| Local share of energy | 0.2 | 0.0 | 1.1 | 0.0 | 1.1 | 1.8 | 0.1 | 0.7 | 0.3 | 0.3 | 1.0 | 1.2 | 1.7 | 0.0 | |
| Quantity of exporting energy | -3458.9 | -6135.0 | 3647.1 | -1862.0 | 4231.8 | 5237.7 | -1340.1 | -930.4 | -5720.1 | -3901.6 | 9806.7 | 2510.6 | 1611.3 | -4688.3 | |
| 2037 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 603.5 | 0.3 | 28664.4 | 0.4 | 37765.7 | 0.0 | 0.1 | 0.3 | 0.9 | 1021.8 | 281560.2 | 15607.1 | 0.3 | 1.1 | 365226.1 |
| Hydro prod. | 219.0 | 148.0 | 6589.0 | 77.4 | 5118.6 | 11623.8 | 133.6 | 1771.5 | 1974.1 | 915.0 | 17720.0 | 1752.0 | 4019.5 | 0.0 | 52061.5 |
| Demand | 4525.5 | 6662.3 | 33245.7 | 2072.3 | 40547.5 | 6798.1 | 1576.9 | 2939.8 | 8048.9 | 5917.4 | 282316.3 | 15619.1 | 2584.1 | 5235.9 | 418089.7 |
| Local share of energy | 0.2 | 0.0 | 1.1 | 0.0 | 1.1 | 1.7 | 0.1 | 0.6 | 0.2 | 0.3 | 1.1 | 1.1 | 1.6 | 0.0 | |
| Quantity of exporting energy | -3703.0 | -6514.0 | 2007.8 | -1994.5 | 2336.7 | 4825.7 | -1443.2 | -1168.0 | -6073.9 | -3980.6 | 16963.8 | 1740.0 | 1435.7 | -5234.8 | |
| 2038 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 478.6 | 0.4 | 32336.9 | 0.6 | 40634.2 | 0.0 | 0.3 | 0.5 | 1.3 | 805.9 | 307946.4 | 18847.6 | 0.6 | 1.5 | 401054.7 |
| Hydro prod. | 219.0 | 148.0 | 6589.0 | 77.4 | 5118.6 | 12224.8 | 133.6 | 1896.5 | 1709.1 | 915.0 | 15947.0 | 1488.0 | 4019.5 | 0.0 | 50485.5 |
| Demand | 4815.1 | 7148.6 | 35539.6 | 2214.2 | 42899.3 | 7236.7 | 1687.3 | 3198.5 | 8419.7 | 6449.9 | 307724.8 | 16759.2 | 2772.7 | 5576.3 | 452441.9 |
| Local share of energy | 0.1 | 0.0 | 1.1 | 0.0 | 1.1 | 1.7 | 0.1 | 0.6 | 0.2 | 0.3 | 1.1 | 1.2 | 1.4 | 0.0 | |
| Quantity of exporting energy | -4117.5 | -7000.2 | 3386.3 | -2136.2 | 2853.5 | 4988.1 | -1553.4 | -1301.5 | -6709.3 | -4729.0 | 16168.6 | 3576.3 | 1247.4 | -5574.8 | |
| 2039 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 454.2 | 0.4 | 35404.1 | 0.6 | 43595.5 | 0.0 | 0.3 | 0.5 | 1.4 | 763.5 | 338000.7 | 18855.4 | 0.6 | 1.6 | 437078.8 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydro prod. | 219.0 | 148.0 | 6589.0 | 77.4 | 5302.6 | 12224.8 | 133.6 | 1896.5 | 1868.9 | 915.0 | 15947.0 | 1643.1 | 4538.5 | 0.0 | 51503.4 |
| Demand | 5123.3 | 7670.4 | 37991.9 | 2365.9 | 45387.5 | 7703.6 | 1805.4 | 3480.0 | 8807.5 | 7030.4 | 335420.0 | 17982.7 | 2975.1 | 5938.7 | 489682.3 |
| Local share of energy | 0.1 | 0.0 | 1.1 | 0.0 | 1.1 | 1.6 | 0.1 | 0.5 | 0.2 | 0.2 | 1.1 | 1.1 | 1.5 | 0.0 | |
| Quantity of exporting energy | -4450.1 | -7522.0 | 4001.2 | -2287.9 | 3510.7 | 4521.2 | -1671.5 | -1583.0 | -6937.2 | -5351.9 | 18527.6 | 2515.8 | 1564.0 | -5937.1 | |
| 2040 | Benin | Burkina | Ivory Coast | Gambia | Ghana | Guinea | Guinea-Bissau | Liberia | Mali | Niger | Nigeria | Senegal | Sierra Leone | Togo | Total |
| Thermal prod. | 488.8 | 1.6 | 38980.6 | 1.7 | 48040.8 | 0.0 | 0.6 | 1.4 | 3.9 | 821.1 | 370597.0 | 19371.1 | 1.8 | 4.1 | 478314.4 |
| Hydro prod. | 219.0 | 148.0 | 6804.0 | 77.4 | 5642.6 | 12574.8 | 133.6 | 1896.5 | 1868.9 | 915.0 | 14510.0 | 1643.1 | 4538.5 | 0.0 | 50971.4 |
| Demand | 5451.2 | 8230.4 | 40613.3 | 2527.9 | 48019.9 | 8200.5 | 1931.8 | 3786.2 | 9213.3 | 7663.1 | 365607.8 | 19295.4 | 3192.3 | 6324.7 | 530057.8 |
| Local share of energy | 0.1 | 0.0 | 1.1 | 0.0 | 1.1 | 1.5 | 0.1 | 0.5 | 0.2 | 0.2 | 1.1 | 1.1 | 1.4 | 0.0 | |
| Quantity of exporting energy | -4743.4 | -8080.8 | 5171.3 | -2448.8 | 5663.5 | 4374.3 | -1797.6 | -1888.3 | -7340.5 | -5927.0 | 19499.1 | 1718.7 | 1348.0 | -6320.6 | |

*Table 36 : Assessment of the energy produced for all countries between 2018 and 2040*

| Countries | Situation in 2018 | Situation in 2040 |
|---|---|---|
| Benin | Demand : 524GWh<br>Load factor : 104.4MW<br>Existing Fleet : Hydraulic power plants = 32.5MW ; Thermal power plants = 163MW<br>**Available energy** : Thermal power plants = 405GWh ; Hydraulic power plants = 113GWh<br>Candidate power plants : CC6 & OCGT8 | Demand : 2180.5GWh<br>Load factor : 434.7MW<br>Existing Fleet : Hydraulic power plants = 109.2MW ; Thermal power plants = 462MW<br>Candidate power plants : 4 CC6 & 1 OCGT8<br>**Available energy :** Thermal power plants = 2046.6GWh ; Hydraulic power plants = 128.3GWh<br>Net present cost : **1229M$**<br>Levelized cost of energy : **0.109$/kWh** |
| Burkina Faso | Demand : 645GWh<br>Load factor : 133.8MW<br>Existing Fleet : Hydraulic power plants = 2MW ; Thermal power plants = 228.8MW<br>**Available energy** : Thermal power plants = 544.1GWh ; Hydraulic power plants = 80GWh<br>Candidate power plants : HFO1, CC6, CC2 & OCGT9 | Demand : 3292.2GWh<br>Load factor : 683.3MW<br>Existing Fleet : Hydraulic power plants = 60.66MW ; Thermal power plants = 869MW<br>Candidate power plants : 1 CC2, 3 CC6 & 1 OCGT9<br>**Available energy** : Thermal power plants = 3056.6GWh ; Hydraulic power plants = 223GWh<br>Net present cost : **2093M$**<br>Levelized cost of energy : **0.164$/kWh** |
| Gambia | Demand : 157GWh<br>Load factor : 29.5MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 69MW<br>**Available energy** : Thermal power plants = 157.6GWh ; Hydraulic power plants = 0GWh<br>Candidate power plants : DDO1, HFO1-2 & OCGT7 | Demand : 1011GWh<br>Load factor : 189.2MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 225.5MW<br>Candidate power plants : 5 DDO1, 5 HFO1 & 6 HFO2<br>**Available energy** : Thermal power plants = 1010.8GWh ; Hydraulic power plants = 0GWh<br>Net present cost : **667M$**<br>Levelized cost of energy : **0.127$/kWh** |
| Guinea-Bissau | Demand : 67.3GWh<br>Load factor : 12.0MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 37MW<br>**Available energy** : Thermal power plants = 405GWh ; Hydraulic power plants = 0GWh<br>Candidate power plants : DDO1, HFO1-2 & OCGT7 | Demand : 773GWh<br>Load factor : 137.8MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 163MW<br>Candidate power plants : 2 DDO1, 5 HFO1 & 4 HFO2<br>Available energy : Thermal power plants = 772.1GWh ; Hydraulic power plants = 0GWh<br>Net present cost : **327M$**<br>Levelized cost of energy : **0.130$/kWh** |
| Liberia | Demand : 149GWh<br>Load factor : 29.3MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 48MW<br>**Available energy** : Thermal power plants = 148GWh ; Hydraulic power plants = 0GWh<br>Candidate power plants : CC5, DDO1, HFO1-2 & OCGT7-8 | Demand : 1514GWh<br>Load factor : 298.1MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 358MW<br>**Available energy** : Thermal power plants = 1512GWh ; Hydraulic power plants = 0GWh<br>Candidate power plants : 5 DDO1, 6 HFO1 & 10 HFO2<br>Net present cost : **536M$**<br>Levelized cost of energy : **0.129$/kWh** |

| | | |
|---|---|---|
| Mali | Demand : 824GWh<br>Load factor : 136MW<br>Existing Fleet : Hydraulic power plants = 54MW ; Thermal power plants = 136MW<br>**Available energy** : Thermal power plants = 563.8GWh ; Hydraulic power plants = 266GWh<br>Candidate power plants : CC5, DDO1 HFO2 & OCGT7 | Demand : 3685GWh<br>Load factor : 610MW<br>Existing Fleet : Hydraulic power plants = 70MW ; Thermal power plants = 705MW<br>**Available energy** : Thermal power plants = 3332GWh ; Hydraulic power plants = 358GWh<br>Candidate power plants : 6 DDO1 & 19 HFO2<br>Net present cost : **2145M$**<br>Levelized cost of energy : **0.140$/kWh** |
| Niger | Demand : 460.4GWh<br>Load factor : 86.2MW<br>Existing Fleet : Thermal power plants = 151.4MW<br>**Available energy** : Thermal power plants = 460.5GWh<br>Candidate power plants : OCGT8, COAL10 & DDO1 | Demand : 3065.2GWh<br>Load factor : 573.8MW<br>Existing Fleet : Hydraulic power plants = 26MW ; Thermal power plants = 746MW<br>Candidate power plants : 2 COAL10, 3 DDO1 & 2 OCGT8<br>**Available energy** : Thermal power plants = 2969GWh ; Hydraulic power plants = 91.1GWh<br>Net present cost : **857M$**<br>Levelized cost of energy : **0.088$/kWh** |
| Togo | Demand : 633GWh<br>Load factor : 100.5MW<br>Existing Fleet : Hydraulic power plants = 32.5MW ; Thermal power plants = 124.5MW<br>**Available energy** : Thermal power plants = 522.7GWh ; Hydraulic power plants = 113GWh<br>Candidate power plants : CC6 & OCGT8 | Demand : 2529.9GWh<br>Load factor : 401.6MW<br>Existing Fleet : Hydraulic power plants = 69.7MW ; Thermal power plants = 470MW<br>Candidate power plants : 4 CC6 & 1 OCGT8<br>**Available energy** : Thermal power plants = 2233GWh ; Hydraulic power plants = 295GWh<br>Net present cost : **995M$**<br>Levelized cost of energy : **0.085$/kWh** |

*Table 37 : 40% of local electricity production for import countries*

| | Situation in 2018 | Situation in 2040 |
|---|---|---|
| ECOWAS | Demand : 83497GWh<br>Load factor : 14374.9MW<br>Existing Fleet : Hydraulic power plants = 4122.5MW ; Thermal power plants = 12060MW<br>**Available energy** : Thermal power plants = 73212GWh ; Hydraulic power plants = 14880GWh<br>Candidate power plants : CC4, NGCC & OCGT9 | Demand : 512006GWh<br>Load factor : 88147.1MW<br>Existing Fleet : Hydraulic power plants = 12973MW ; Thermal power plants = 82447MW<br>Candidate power plants : 65 CC4, 41 NGCC & 109 OCGT9<br>**Available energy :** Thermal power plants = 460838GWh ; Hydraulic power plants = 51347GWh<br>Net present cost : **128492M$**<br>Levelized cost of energy : **0.060$/kWh** |

*Table 38 : Production fleet for the sub-region*

| Countries | Situation in 2018 | Situation in 2040 |
|---|---|---|
| Benin | Demand : 786GWh<br>Load factor : 156.6MW<br>Existing Fleet : Hydraulic power plants = 32.5MW ; Thermal power plants = 163MW<br>**Available energy** : Thermal power plants = 405GWh ; Hydraulic power plants = 113GWh<br>Candidate power plants : CC6 & OCGT8 | Demand : 3270.8GWh<br>Load factor : 652.1MW<br>Existing Fleet : Hydraulic power plants = 53.2MW ; Thermal power plants = 742MW<br>Candidate power plants : 7 CC6 & 2 OCGT8<br>**Available energy :** Thermal power plants = 3191.3GWh ; Hydraulic power plants = 70GWh<br>Net present cost : **1682M$**<br>Levelized cost of energy : **0.098$/kWh** |
| Burkina Faso | Demand : 967.5GWh<br>Load factor : 200.8MW<br>Existing Fleet : Hydraulic power plants = 2MW ; Thermal power plants = 228.8MW<br>**Available energy** : Thermal power plants = 544.1GWh ; Hydraulic power plants = 80GWh<br>Candidate power plants : HFO1, CC6, CC2 & OCGT9 | Demand : 4938.3GWh<br>Load factor : 1024.6MW<br>Existing Fleet : Hydraulic power plants = 49.9MW ; Thermal power plants = 1169MW<br>Candidate power plants : 1 CC2, 6 CC6 & 2 OCGT9<br>**Available energy** : Thermal power plants = 4723.7GWh ; Hydraulic power plants = 195.7GWh<br>Net present cost : **3044M$**<br>Levelized cost of energy : **0.153$/kWh** |
| Gambia | Demand : 236GWh<br>Load factor : 44.2MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 69MW<br>**Available energy** : Thermal power plants = 157.6GWh ; Hydraulic power plants = 0GWh<br>Candidate power plants : DDO1, HFO1-2 & OCGT7 | Demand : 1517GWh<br>Load factor : 283.8MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 335.5MW<br>Candidate power plants : 4 DDO1, 5 HFO1 & 12 HFO2<br>**Available energy** : Thermal power plants = 1516.1GWh ; Hydraulic power plants = 0GWh<br>Net present cost : **978M$**<br>Levelized cost of energy : **0.121$/kWh** |
| Guinea-Bissau | Demand : 100.9GWh<br>Load factor : 18.0MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 37MW<br>**Available energy** : Thermal power plants = 405GWh ; Hydraulic power plants = 0GWh<br>Candidate power plants : DDO1, HFO1-2 & OCGT7 | Demand : 1159GWh<br>Load factor : 206.7MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 257MW<br>Candidate power plants : 3 DDO1, 5 HFO1 & 7 HFO2<br>Available energy : Thermal power plants = 1157.6GWh ; Hydraulic power plants = 0GWh<br>Net present cost : **495M$**<br>Levelized cost of energy : **0.125$/kWh** |
| Liberia | Demand : 223.6GWh<br>Load factor : 44.0MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 48MW<br>**Available energy** : Thermal power plants = 148GWh ; Hydraulic power plants = 0GWh<br>Candidate power plants : CC5, DDO1, HFO1-2 & OCGT7-8 | Demand : 2272GWh<br>Load factor : 447.0MW<br>Existing Fleet : Hydraulic power plants = 0MW ; Thermal power plants = 528MW<br>**Available energy** : Thermal power plants = 1512GWh ; Hydraulic power plants = 0GWh<br>Candidate power plants : 5 DDO1, 6 HFO1 & 10 HFO2<br>Net present cost : **800M$**<br>Levelized cost of energy : **0.125$/kWh** |

| | | |
|---|---|---|
| Mali | Demand : 1236GWh<br>Load factor : 205MW<br>Existing Fleet : Hydraulic power plants = 54MW ; Thermal power plants = 136MW<br>**Available energy** : Thermal power plants = 563.8GWh ; Hydraulic power plants = 266GWh<br>Candidate power plants : CC5, DDO1 HFO2 & OCGT7 | Demand : 5528GWh<br>Load factor : 915MW<br>Existing Fleet : Hydraulic power plants = 70MW ; Thermal power plants = 1054.8MW<br>**Available energy** : Thermal power plants = 5203.8GWh ; Hydraulic power plants = 309GWh<br>Candidate power plants : 11 DDO1 & 34 HFO2<br>Net present cost : **3337M$**<br>Levelized cost of energy : **0.138$/kWh** |
| Niger | Demand : 690.6GWh<br>Load factor : 129.3MW<br>Existing Fleet : Thermal power plants = 151.4MW<br>**Available energy** : Thermal power plants = 460.5GWh<br>Candidate power plants : OCGT8, COAL10 & DDO1 | Demand : 4597.5GWh<br>Load factor : 860.7MW<br>Existing Fleet : Hydraulic power plants = 26MW ; Thermal power plants = 1006MW<br>Candidate power plants : 4 COAL10, 4 DDO1 & 2 OCGT8<br>**Available energy** : Thermal power plants = 2969GWh ; Hydraulic power plants = 91.1GWh<br>Net present cost : **1273M$**<br>Levelized cost of energy : **0.082$/kWh** |
| Togo | Demand : 949.5GWh<br>Load factor : 150.8MW<br>Existing Fleet : Hydraulic power plants = 32.5MW ; Thermal power plants = 124.5MW<br>**Available energy** : Thermal power plants = 522.7GWh ; Hydraulic power plants = 113GWh<br>Candidate power plants : CC6 & OCGT8 | Demand : 3794.9GWh<br>Load factor : 602.4MW<br>Existing Fleet : Hydraulic power plants = 122.3MW ; Thermal power plants = 712.3MW<br>Candidate power plants : 6 CC6 & 1 OCGT8<br>**Available energy** : Thermal power plants = 3344.5GWh ; Hydraulic power plants = 454.8GWh<br>Net present cost : **1514M$**<br>Levelized cost of energy : **0.084$/kWh** |

*Table 39 : 60% of local electricity production for import countries*

| | Situation in 2018 | Situation in 2040 |
|---|---|---|
| ECOWAS | Demand : 86417GWh<br>Load factor : 14092.8MW<br>Existing Fleet : Hydraulic power plants = 4122.5MW ; Thermal power plants = 12060MW<br>**Available energy** : Thermal power plants = 71492GWh ; Hydraulic power plants = 14880GWh<br>Candidate power plants : CC4, NGCC & OCGT9 | Demand : 502981GWh<br>Load factor : 82025.6MW<br>Existing Fleet : Hydraulic power plants = 12839MW ; Thermal power plants = 79329MW<br>Candidate power plants : 63 CC4, 40 NGCC & 106 OCGT9<br>**Available energy :** Thermal power plants = 451636GWh ; Hydraulic power plants = 51461GWh<br>Net present cost : **125760M$**<br>Levelized cost of energy : **0.060$/kWh** |

*Table 40 : Production fleet for the sub-regionRenewable energies : 4th variant*

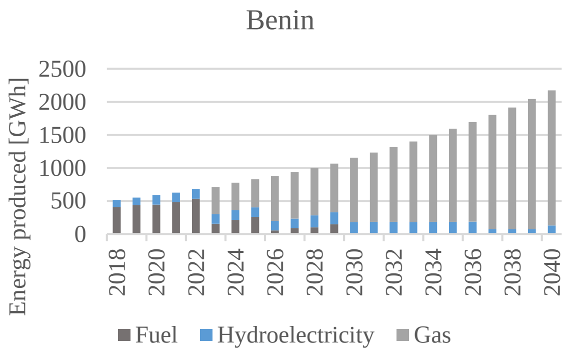


*Figure 66 : Local production in Benin (2nd Variant)*

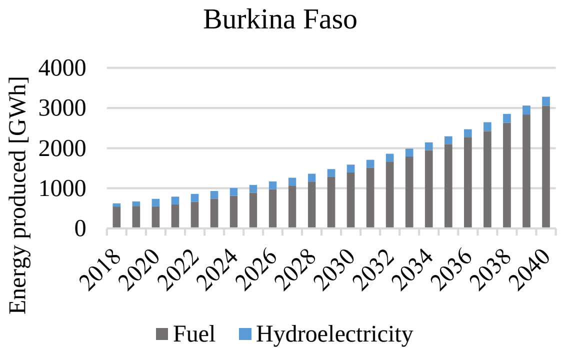


*Figure 67 : Local production in Burkina Faso (2nd Variant)*

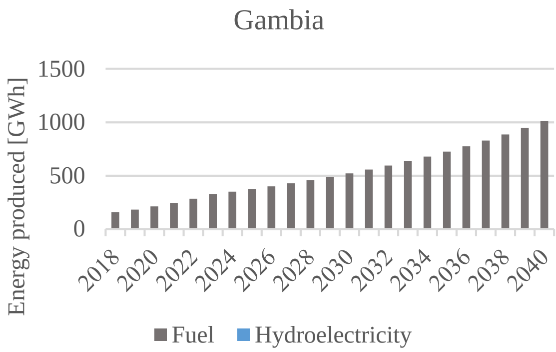


*Figure 68 : Local production in Gambia (2nd Variant)*

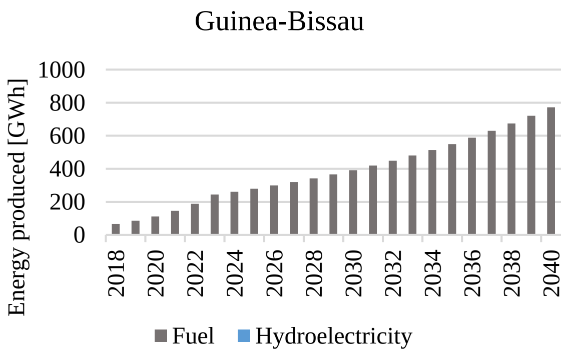


*Figure 69 : Local production in Guinea-Bissau (2nd Variant)*

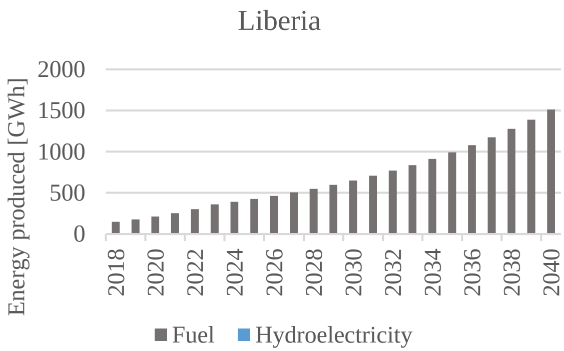


*Figure 70 : Local production in Liberia (2nd Variant)*

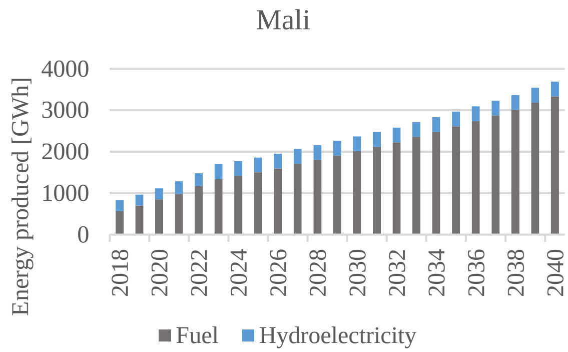


*Figure 71 : Local production in Mali (2nd Variant)*

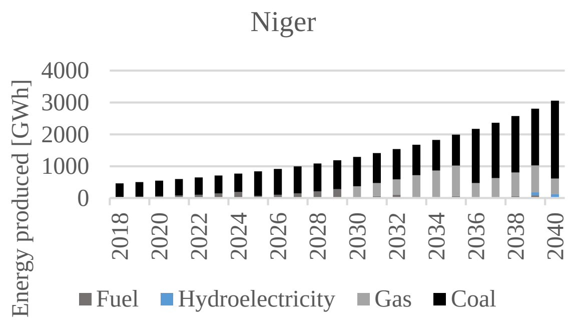


*Figure 72 : Local production in Niger (2nd Variant)*

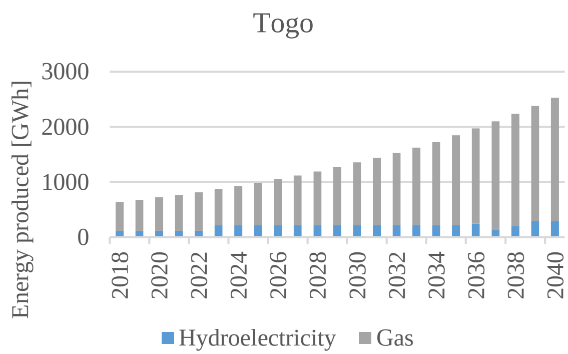

*Figure 73 : Local production in Togo (2nd Variant)*

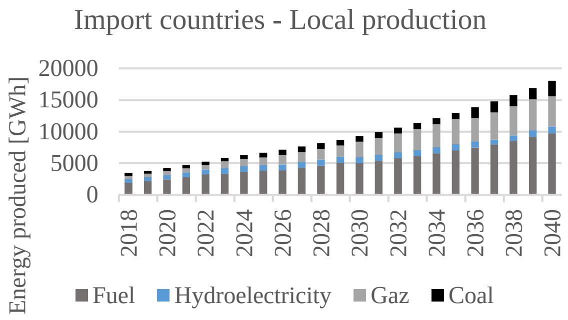


*Figure 74 : Local production in Import countries (2nd Variant)*

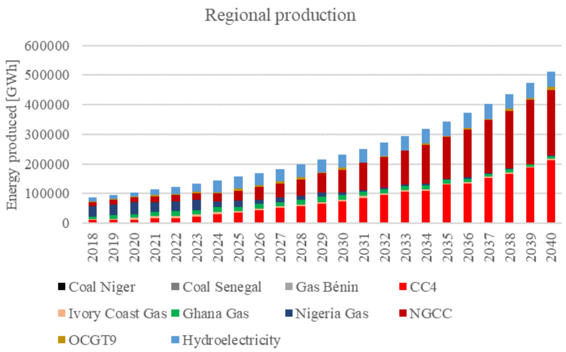


*Figure 75 : Regional energy production (2nd Variant)*

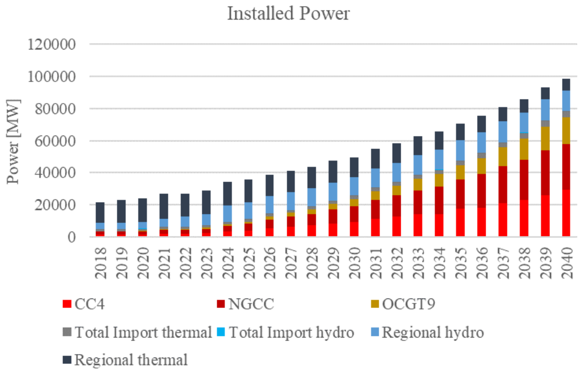


*Figure 76 : Regional installed power (2nd Variant)*

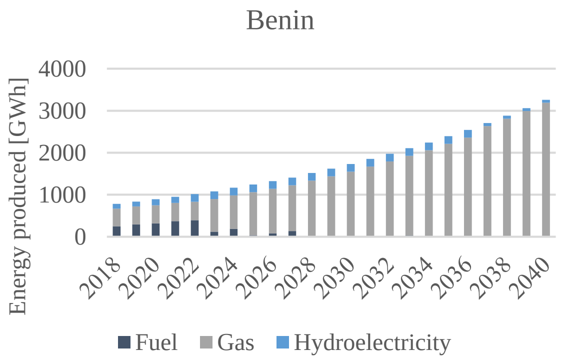


*Figure 77 : Local production in Benin (3rd Variant)*

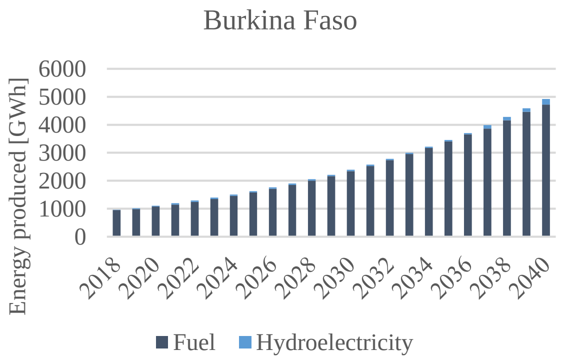


*Figure 78 : Local production in Burkina Faso (3rd Variant)*

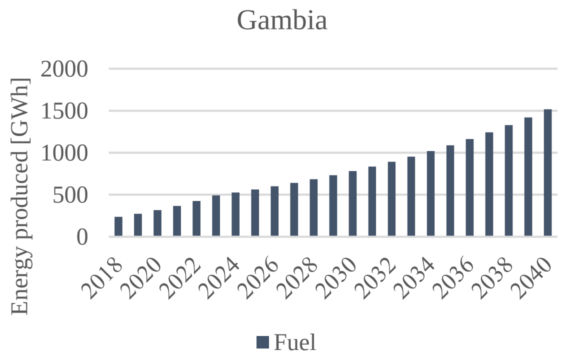


*Figure 79 : Local production in Gambia (3rd Variant)*

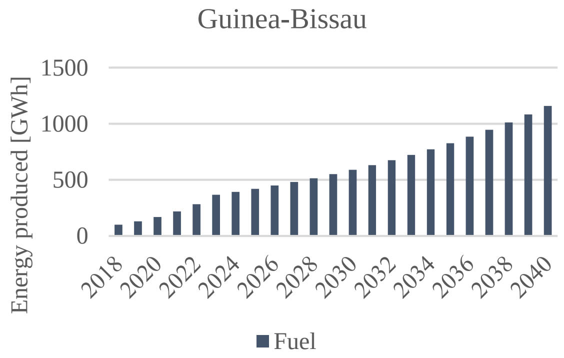


*Figure 80 : Local production in Guinea-Bissau (3rd Variant)*

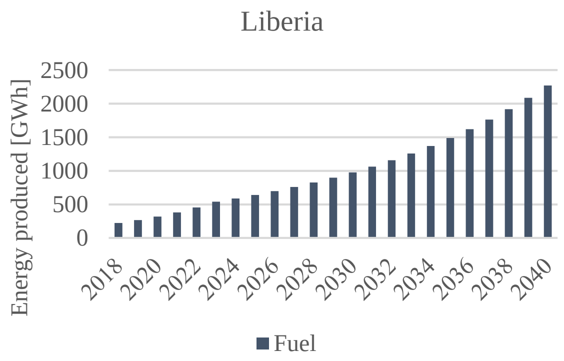


*Figure 81 : Local production in Liberia (3rd Variant)*

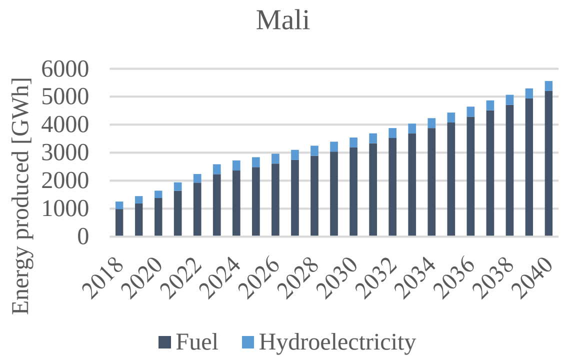


*Figure 82 : Local production in Mali (3rd Variant)*

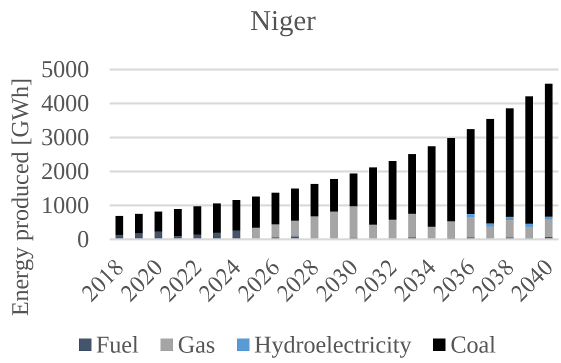


*Figure 83 : Local production in Niger (3rd Variant)*

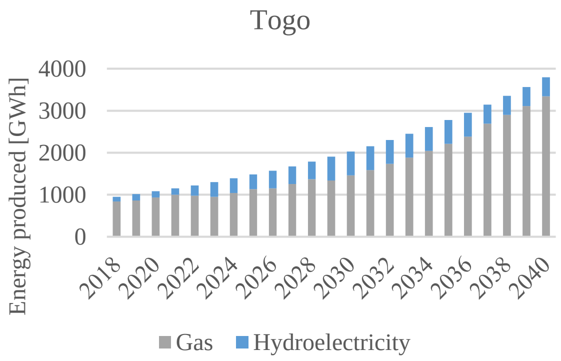


*Figure 84 : Local production in Togo (3rd Variant)*

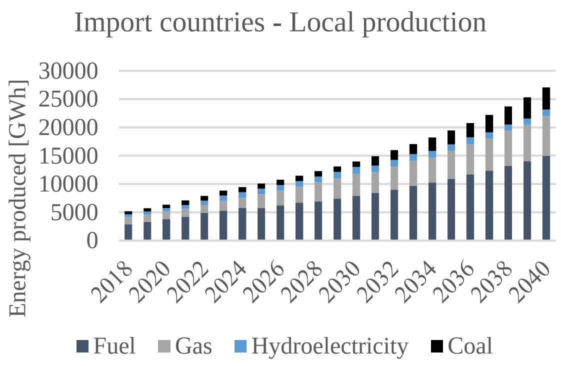


*Figure 85 : Local production in import countries (3rd Variant)*

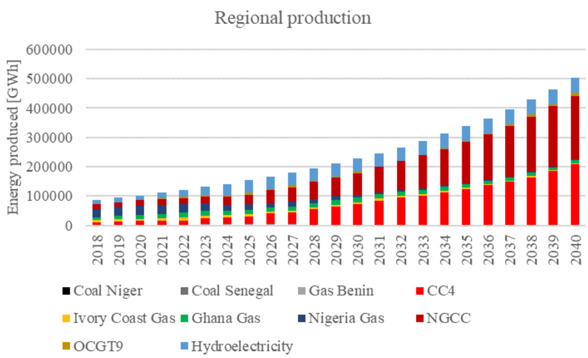


*Figure 86 : Regional energy production (3rd Variant)*

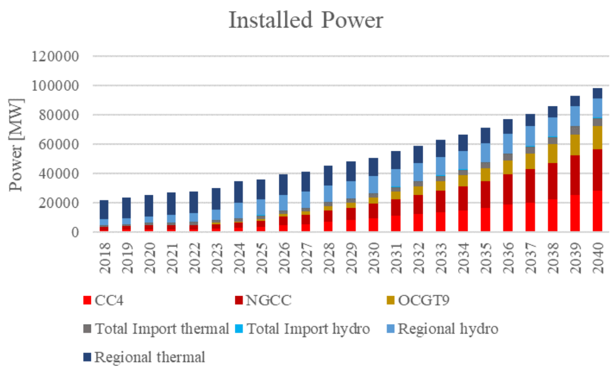


*Figure 87 : Regional installed power (3rd Variant)*

| **Self Sufficiency strategy** [GWh] | | | | |
|---|---|---|---|---|
| | Fuel | Gas | Coal | Hydroelectricity |
| 2018 | 6691 | 62676 | 466 | 19320 |
| 2019 | 7379 | 68754 | 544 | 18406 |
| 2020 | 8071 | 62035 | 15683 | 18047 |
| 2021 | 6249 | 69801 | 15550 | 22941 |
| 2022 | 7929 | 75776 | 17312 | 23839 |
| 2023 | 7988 | 85206 | 16867 | 25430 |
| 2024 | 8025 | 95243 | 17129 | 26558 |
| 2025 | 8782 | 107085 | 16886 | 26685 |
| 2026 | 7922 | 115193 | 20554 | 29621 |
| 2027 | 9631 | 127556 | 20388 | 30240 |
| 2028 | 12134 | 144150 | 17726 | 29679 |
| 2029 | 13339 | 158393 | 19157 | 30174 |
| 2030 | 14905 | 166688 | 16775 | 41970 |
| 2031 | 13995 | 195821 | 7693 | 42963 |
| 2032 | 16347 | 211410 | 11140 | 42898 |
| 2033 | 14266 | 237997 | 8562 | 43832 |
| 2034 | 14430 | 260598 | 9909 | 44726 |
| 2035 | 16524 | 282348 | 12900 | 45284 |
| 2036 | 17557 | 311576 | 11776 | 45686 |
| 2037 | 18034 | 342542 | 11068 | 46820 |
| 2038 | 19194 | 376953 | 11360 | 46048 |
| 2039 | 20510 | 410706 | 11659 | 48170 |
| 2040 | 22180 | 450854 | 11231 | 47233 |

*Table 41 : Evolution of the energy produced by fuel type*

| **Single regional market strategy** [GWh] | | | | |
|---|---|---|---|---|
| | Fuel | Gas | Coal | Hydroelectricity |
| 2018 | 0 | 75554 | 463 | 15364 |
| 2019 | 0 | 83585 | 464 | 15364 |
| 2020 | 0 | 91592 | 1266 | 15292 |
| 2021 | 1 | 95827 | 2595 | 19739 |
| 2022 | 9 | 101226 | 2606 | 24847 |
| 2023 | 5 | 108725 | 2595 | 28992 |
| 2024 | 0 | 108157 | 2521 | 40781 |
| 2025 | 0 | 119275 | 2513 | 41755 |
| 2026 | 0 | 132079 | 2400 | 42169 |
| 2027 | 0 | 145365 | 2396 | 42971 |
| 2028 | 0 | 160687 | 2207 | 43178 |
| 2029 | 0 | 176433 | 2181 | 44200 |
| 2030 | 0 | 193911 | 2314 | 44583 |
| 2031 | 0 | 212924 | 1499 | 45939 |
| 2032 | 0 | 233372 | 1445 | 46682 |
| 2033 | 0 | 255316 | 1296 | 47812 |
| 2034 | 0 | 278974 | 1256 | 49155 |
| 2035 | 2 | 304382 | 1621 | 50233 |
| 2036 | 2 | 332668 | 1448 | 51289 |
| 2037 | 8 | 363711 | 1508 | 52061 |
| 2038 | 12 | 399855 | 1188 | 50485 |
| 2039 | 14 | 435942 | 1123 | 51503 |
| 2040 | 40 | 477068 | 1206 | 50971 |

*Table 42 : Evolution of the energy produced by fuel type*